DETERMINATION OF THE HYDRAULIC CONDUCTIVITY OF THE ALACHUA COUNTY SOUTHWEST LANDFILL

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Slug tests were conducted in the existing gas vents of the municipal landfill of Alachua County, Florida, for the purpose of determining the hydraulic conductivity of the landfilled municipal solid waste. The Bouwer and Rice method of analysis was applied. Two types of slug tests were conducted: a conventional method with a volumetric slug and a new method with the removal of a slug by means of a submersible pump. The conventional method measured the hydraulic conductivity of the 24-inch diameter gravel pack and was unsuccessful for the measurement of the municipal solid waste. The pumped slug method successfully simulated the instantaneous removal necessary to hydraulically impact the municipal solid waste.

The geometric mean of the late time response of the pump slug tests, 3.2×10^{-4} cm/sec, is the best representation of the horizontal hydraulic conductivity, K_h, of the municipal solid waste in the vicinity of the gas vents tested. The

ranged 6.7 x 10^{-5} to 9.8 x 10^{-4} cm/sec. The range of values can be attributed to the heterogeneities of landfilled municipal solid waste.

CHAPTER 1
INTRODUCTION

Landfilling is the primary means of solid waste disposal in the United States. Incineration, although an ultimate disposal option, is hindered by public opposition, high capital costs, and regulatory uncertainty. Recycling and composting, although important to integrated solid waste management strategies, have yet to significantly reduce the volume of the solid waste stream. In 1988, 72.7% (by weight), or 400 million cubic yards, of the nation's discards were deposited in 6,500 municipal solid waste (MSW) landfills (U. S. Environmental Protection Agency (U. S. EPA), 1990). The remaining 27.3% was incinerated or recovered for the purpose of recycling and/or composting. However, not all materials recovered were ultimately recycled. If markets for the recovered material were saturated or not available, the recovered materials were stored, or in some cases sent to a landfill or incinerator. In the state of Florida, 19.4 million tons of MSW was generated in 1990, 69% (by weight) of which was deposited in the state's 150 active landfills (Florida Department of Environmental Regulation (FL DER), 1991) (See Figure 1-1). Despite the nation's efforts to reduce the solid waste stream and statewide efforts, such as Florida's aggressive goal of 30% recycling by 1995 established

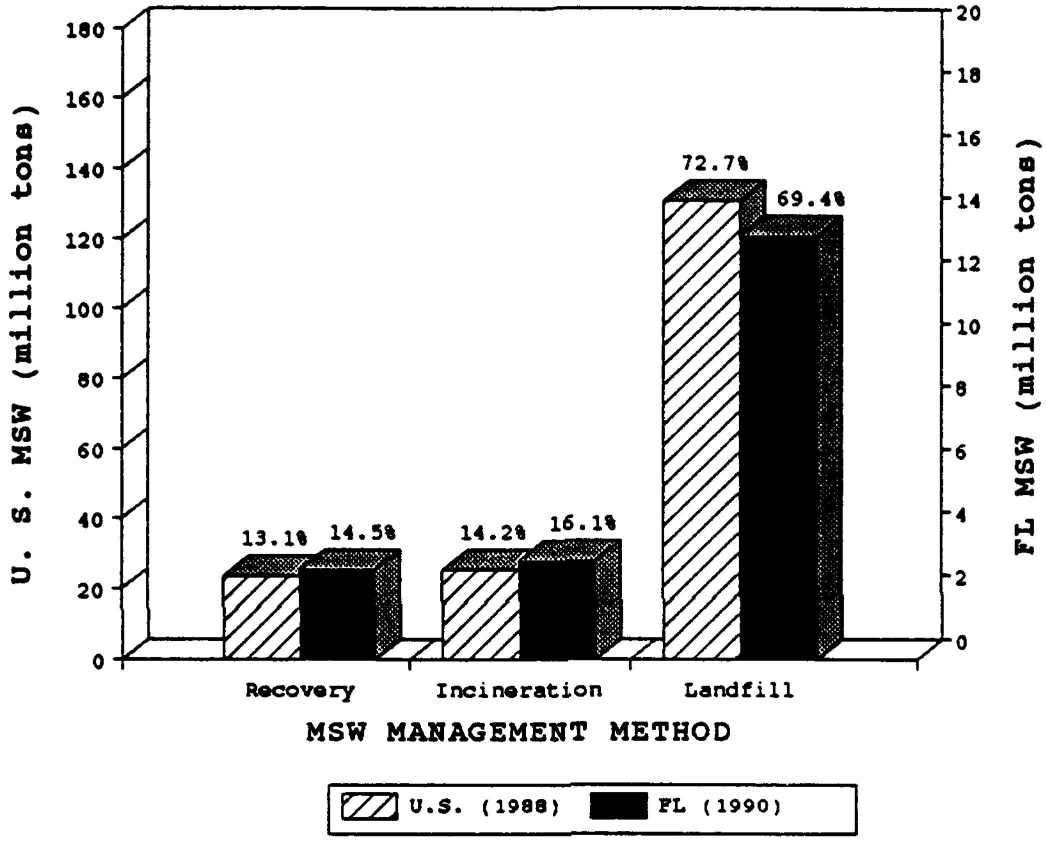

Figure 1-1. MSW Management in U.S. and Florida

in the 1988 Solid Waste Management Act (SWMA), landfills remain the most viable means of solid waste disposal.

Born of the sheer magnitude of the waste disposal problem and the necessity to protect the nation's drinking water sources from the impacts of landfilling, Subtitle D regulations issued by the U. S. EPA in 1991 under the authority of the Resource Conservation and Recovery Act (RCRA) specifically addresses the siting, design, operation, and groundwater monitoring of newly constructed landfills. New MSW landfills are required to install liners and leachate control and collection systems. An accurate assessment of the hydrologic characteristics of MSW is critical to the design of these systems.

The purpose of this project was to determine the hydraulic conductivity of municipal solid waste at a landfill. Slug tests were performed utilizing landfill gas vents, and the results were evaluated by the Bouwer and Rice method (Bouwer and Rice, 1976; Bouwer, 1989).

CHAPTER 2
LITERATURE REVIEW

Introduction

Many of the studies found in the literature regarding the nature of MSW leachate focus primarily on the effects of MSW composition and processing on leachate generation and leachate quality, the effects of leachate recycle, and the effects of leachate generation on landfill liner design. The determination of the hydraulic conductivity represents only a small fraction of the reported research efforts. The results of these investigations are presented here. First, a review of the principles of hydraulic conductivity and the factors which influence the hydraulic conductivity of MSW are presented. Then, the applied laboratory methods, field methods, and empirical models which report values for the hydraulic conductivity of MSW are reviewed. Lastly, an alternate method selected for this study is presented.

Hydraulic Conductivity

Saturated Flow

Henry Darcy, a French civil engineer, conducted the first systematic study of the movement of water through a porous medium in 1856. He demonstrated that the rate of water flow through a saturated porous medium, q (L/T), is proportional to

the hydraulic gradient, i (L/L)

$$q = -K_s i \tag{2-1}$$

where K_s (L/T) is a proportionality constant called the hydraulic conductivity. The saturated hydraulic conductivity, K_s, is typically expressed in units of centimeters per second. The negative sign indicates that flow is in the direction of decreasing hydraulic head (Freeze and Cherry, 1979).

By experimentally varying fluid density, viscosity, and the geometrical properties of sands, Hubbert (1956, as cited in Domenico and Schwartz, 1990) demonstrated that Darcy's constant of proportionality, K_s, could be written as

$$K_s = \frac{k \rho_w d^2}{\mu} \tag{2-2}$$

where k is the intrinsic permeability, ρ_ω is the fluid density, μ is the fluid viscosity, and d is the mean grain diameter of the medium. The intrinsic permeability represents the ability of the medium to transmit a specific fluid, whereas the hydraulic conductivity represents the ability of a medium to transmit water (Domenico and Schwartz, 1990). Table 2-1 indicates the range of values of hydraulic conductivity for a variety of geological materials.

Darcy's equation is valid for flow in the unsaturated zone, but the unsaturated hydraulic conductivity, K_u, is not a constant. The most widely accepted relationship between unsaturated hydraulic conductivity and volumetric moisture

Table 2-1. Representative Values of Hydraulic Conductivity for Rocks and Unconsolidated Material

Type of Material	Hydraulic Conductivity (cm/sec)
Gravel	$3 \times 10^{-2} - 3$
Coarse sand	$9 \times 10^{-5} - 6 \times 10^{-1}$
Medium sand	$9 \times 10^{-5} - 5 \times 10^{-2}$
Fine sand	$2 \times 10^{-5} - 2 \times 10^{-2}$
Silt, loess	$1 \times 10^{-7} - 2 \times 10^{-3}$
Till	$1 \times 10^{-10} - 2 \times 10^{-4}$
Clay	$1 \times 10^{-9} - 4.7 \times 10^{-9}$
Karst and reef limestone	$1 \times 10^{-4} - 2$
Limestone and dolomite	$1 \times 10^{-7} - 6 \times 10^{-4}$
Sandstone	$3 \times 10^{-8} - 6 \times 10^{-4}$
Siltstone	$1 \times 10^{-9} - 1.4 \times 10^{-6}$

(source: Domenico and Schwartz, 1990)

content is

$$K_u = K(\theta) = K_s(\theta/\theta_s)^B \tag{2-3}$$

where θ_s is the saturated moisture content (vol/vol) and B represents an empirical constant related to the medium (Ahmed et al. 1992, Noble and Nair, 1990, and Demetracopoulos et al. 1986). As θ increases, more pores fill with water and the rate of downward water movement increases nonlinearly.

Hydraulic Conductivity of MSW

The hydraulic conductivity of a porous medium is a function of both the fluid properties of the liquid and the physical properties of the medium. The fluid properties of the liquid that affect the hydraulic conductivity are viscosity and density. The physical properties of the porous medium that affect the hydraulic conductivity are particle shape, size, and size distribution; pore size and pore size distribution, fissures, joints, stratifications and other discontinuities (Sowers, 1979). The fluid properties of leachate and the physical properties of MSW that affect the hydraulic conductivity of MSW are presented here.

Leachate Fluid Properties

As previously mentioned, the fluid properties affecting the hydraulic conductivity of a porous medium are viscosity and density. Both the viscosity and the density of a fluid are functions of the fluid temperature. For instance, as the temperature of water increases, the viscosity decreases and the density slightly decreases at temperatures greater than 4°C. Although landfill temperatures are typically higher than

ambient soil temperatures at the same depth (Fungaroli and Steiner, 1979), the effects of the leachate viscosity and density on the hydraulic conductivity of landfills are not discussed in the literature.

MSW Physical Properties

The physical properties of MSW that affect the hydraulic conductivity of landfilled MSW are degree of proce g, landfill operations, and MSW composition. The degree of processing includes factors such as particle size, compaction, and density. Landfill operations include practices such as the placement of MSW, the thickness of the cover soil, and the type of cover soil. Factors unique to the internal hydrologic processes of the landfill which also affect the hydraulic conductivity are the moisture content, degree of biodegradation, MSW composition, age of the landfill, and depth within the landfill.

Degree of processing. Several studies evaluated the effects of processing on MSW hydraulic conductivity. Fungaroli and Steiner (1979) found that shredding of MSW and compacting to a density of 570 lb/yd^3 had no significant effect on K_s. They did, however, conclude that the density was inversely proportional to the hydraulic conductivity. Miller and others (1989) concluded that K_s could be significantly increased at compaction rates less than 872 lb/yd^3. For compaction rates greater than 872 lb/yd^3, the decrease in K_s was insignificant.

As part of their study to evaluate the effects of processing on MSW moisture retention, Kemper and Smith (1981) demonstrated that dual processing of MSW by baling and shredding produced less leachate than baling alone. The authors attributed this finding to the densely-compacted bales of shredded MSW. The combination of baling and shredding of MSW also produced a more dilute leachate than baled MSW. The authors attributed the dilute leachate to the inhibited moisture infiltration of the more compacted unsaturated shredded bales. The maximum moisture content of MSW before saturated flow begins is defined as field capacity (Lu et al. 1981). Any additional moisture added to MSW at field capacity will cause leachate movement through the refuse (Walsh and Kinman, 1981). At moisture contents less than field capacity, leachate may channel through the pores of less compacted MSW.

Overall, Kemper and Smith (1981) found that for single-processed MSW, baled MSW produced the largest volume of leachate followed by shredded MSW and unprocessed MSW respectively. The most concentrated leachate emanated from the shredded MSW. Kemper and Smith (1981) also found that for single-processed MSW, shredding enhanced the rate of moisture infiltration thereby accelerating the decomposition process and increasing the number of sites available for biological and chemical activity whereas baling inhibited moisture infiltration resulting in a more dilute leachate. Contrary to this finding, Pohland (1986) reported that MSW particle size had no effect on the rate of biodegradation.

The density of MSW increases with depth within the landfill matrix. EMCON Associates (1983) estimated a 30% increase in apparent density from the time of initial placement to the time of site closure (10 years) for MSW deposited at a depth of seven feet. Oweis et al. (1990) suggested that both MSW density and decomposition increase with landfill depth resulting in a decreasing hydraulic conductivity as a function of depth within a landfill.

The more dense the MSW is compacted, the less permeable it becomes to moisture infiltration. The type of equipment used and the initial moisture content of the MSW at the time of placement in the landfill will affect the degree of compaction. Higher compaction rates can be achieved by pre-wetting the MSW (Tchobanoglous, et al. 1977).

Landfill operations. Landfill operations such as the type of cover material, watering prior to compaction, daily variations in compaction and cell construction, and variations in MSW composition (e.g. construction debris, white goods, yard waste, municipal sludge) will increase the heterogeneities within the landfill and therefore affect the hydraulic conductivity of the MSW. Typically, waste layers are deposited in highly compacted layers eight to ten feet thick followed by a more permeable daily cover of soil six to twelve inches thick. The daily cover is necessary to minimize flies, rodents, odors, and blowing debris.

MSW composition. The composition of the MSW will also affect the hydraulic conductivity. Disposal of large items

such as white goods, tires, construction debris, and engine blocks will increase the hydraulic conductivity of the waste (Oweis, 1990). These types of wastes are more typical of older landfill deposits. Current landfill practices segregate these items from the bulk of the MSW deposited. High volumes of plastics in shredded wastes will also increase the hydraulic conductivity. Miller et al. (1989) demonstrated a twofold decrease in the hydraulic conductivity after the removal of plastics which represented 14.2% of the MSW they sampled.

The degree of processing, landfill operations, and MSW composition for a given site must be integrated with the site specific characteristics to assess properly the in situ hydraulic conductivity of a landfill. There are a variety of methods to determine the hydraulic conductivity of porous media. The most common methods have all been utilized for the determination of MSW hydraulic conductivity.

Applied Methods for MSW K Measurement

Hydraulic conductivity can be measured by means of laboratory tests and field tests. Both of these methods have been used to determine the hydraulic conductivity of MSW. A summary of the methods and the results as applied to MSW for each method follows. The results of these studies are summarized in Table 2-2.

Laboratory Methods

Laboratory methods can be one of two tests: constant-head permeameter tests or falling-head permeameter tests.

Table 2-2. Summary of MSW Hydraulic Conductivity Values Determined from Laboratory and Field Methods

Author(s)	Method	Sample Description	Dry Density (lb/yd^3)	Moisture Content (% dry weight)	Hydraulic Conductivity (cm/sec)
Fungaroli and Steiner (1979)	Constant-Head Permeameter	mini-lysimeters emplaced 2 yrs., hand compacted, shredded D(50) = 0.89 mm	532	8.6 %	1.0E-04 - 1.1E-02
		D(50) = 3.20 mm	504	16.6 %	2.0E-04 - 1.1E-02
			523	16.5 %	
			650	16.7 %	
			737	16.5 %	
		D(50) = 13.5 mm	520	20.5 %	5.0E-04 1.8E-02
		D(50) = 0.89 mm	520	20.5 %	2.0E-03 2.1E-02
Korfiatis et al. (1984)	Constant-head Permeameter	mini-lysimeter emplaced 6 mon. unprocessed	1038	20 - 30 %	8.0E-03 1.3E-02
Miller et al. (1989)	Constant-Head Permeameter	newly generated	793	16.3 - 32.3 %	7.5E-04 1.8E-03
		shredded	872		5.6E-04 1.3E-03
		1 - 3 in.	969		4.6E-04 7.9E-04
Oweis et al. (1990)	Falling-head Permeameter	unprocessed landfilled, 7(+) yrs.	1620-2430	Not Reported	1.5E-04
Townsend (1992)	Infiltration Ponds	landfilled 3 (+) yrs.	1300-1400	17 - 35% (a)	5.0E-06 1.0E-05
Oweis et al. (1990)	Test Pit	landfilled 7 (+) yrs.	1080-1620	Not Reported	1.1E-03
EMCON Ass. (1983)	Open-End Borehole	landfilled 10 yrs.	1260	Not Reported	1E-02 4E-02
Oweis et al. (1990)	Pumping Test	landfilled 7 (+) yrs.	1080-1620	Not reported	1E-03 2.5E-03

(a) % wet weight

Typically, constant-head permeameters are used for materials with relatively high hydraulic conductivities such as sands and gravels. Falling-head permeameters are used for materials of relatively low hydraulic conductivity because the seepage rate is so small that any leaks or evaporation could be greater than the flow through the material (Sowers, 1979). Laboratory measurements of K_s for MSW from both permeameter tests are cited in the literature. A brief description of these tests and a discussion of the authors' results follows.

Constant-head permeameter test. In the constant-head test, constant pressure heads are maintained at both the inflow and the outflow ends of the sample. At the start of the test, a valve at the base of the sample is opened and the water begins to flow (See Figure 2-1). After a sufficient volume of water is collected, the volumetric flow rate Q is measured. For a sample of length L and a cross-sectional area A, the hydraulic conductivity is determined by

$$K_s = \frac{QL}{Ah} \qquad (2\text{-}4)$$

where h is the constant head differential.

Fungaroli and Steiner (1979) conducted one of the first studies on the internal behavior of sanitary landfills under laboratory and field conditions. As part of the study, the K_s of shredded MSW was measured as a function of average particle size and density. Although they were unable to establish a significant relationship between the K_s and shredded refuse size, they concluded that the K_s was inversely proportional to

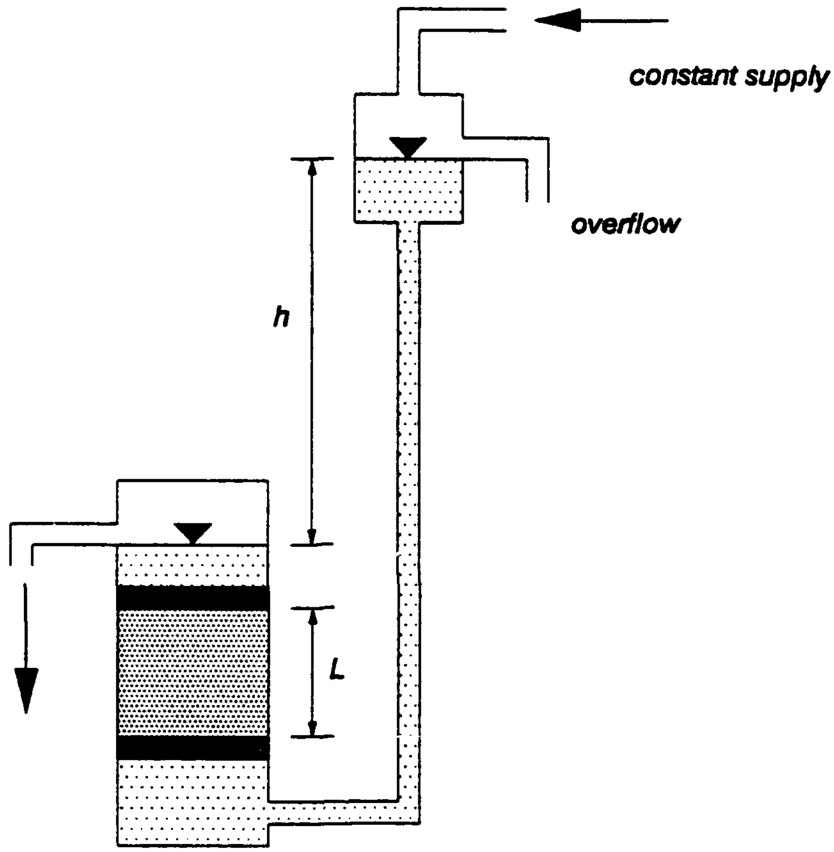

Figure 2-1. Constant-head Permeameter
(source: Domenico and Schwartz, 1990)

density. For shredded MSW, the K_s ranged from 2.0 x 10^{-4} cm/sec at a high density (737 lb/ft^3) and 1.1 x 10^{-2} cm/sec at a low density (504 lb/ft^3). The large variation in the results was attributed to the sample size, effects of the permeameter sidewalls, and refuse characteristics. The samples were collected from mini-lysimeters (55-gal drums), which contained hand compacted MSW shredded to an effective particle diameter (D_{50}) ranging from 3.5 to 13.5 mm, and emplaced for two years under simulated field conditions. The samples collected for the constant-head permeameter test were initially saturated and then hand compacted into the permeameter test cylinders.

Miller et al. (1989) also conducted constant-head permeameter tests on shredded refuse. As part of their research on the anaerobic bioconversion of campus-generated waste at the University of Florida, they determined the K_s of fresh campus solid waste prior to emplacement in laboratory-scale digestors. An assessment of the K_s was critical to optimize the degree of anaerobic degradation. The authors' sampling method was much different than Fungaroli and Steiner's (1979). The shredded campus refuse samples were hand compacted into glass permeameter cylinders followed by a soaking period prior to the start of the constant-head test in lieu of the wet compaction method of Fungaroli and Steiner (1979). The purpose of the soaking period was to simulate actual landfill conditions. The most significant findings were that (1) K_s increased as a function of the soaking

period, and (2) for a given soaking period K_s decreased as a function of the packing density. The first finding suggests that in the absence of complete saturation of the sample, the hydraulic conductivity will be lower. Mitchell et al. (1965 as cited in Oweis and Khera, 1990) reported an increase in hydraulic conductivity by a factor of four to five as the degree of saturation increased from 85 to 98%. Miller et al. also concluded that K_s was inversely proportional to MSW density at values less than 872 lb/yd^3. For densities greater than 872 lb/yd^3, the decrease in K_s was insignificant. Miller et al. (1989) also demonstrated that the removal of plastics, 14.2% of the campus waste stream, decreased the K_s of shredded refuse (969 lb/yd^3) twofold from an average of 6.1 x 10^{-4} cm/sec to an average of 2.9 x 10^{-4} cm/sec.

Korfiatis et al. (1984) conducted a study in a 124-gallon cylindrical mini-lysimeter with unprocessed MSW approximately six months old and a dry density of 1038 lb/yd^3. The tests yielded values of saturated hydraulic conductivity that ranged from 8 x 10^{-3} to 1.3 x 10^{-2} cm/sec which were much higher than those found in the literature. The high values were attributed to laboratory conditions. On the basis of their tests, Korfiatis and Demtracopoulos (1986) selected a K_s value of 1.27 x 10^{-2} cm/sec to calibrate and verify a mathematical model for leachate flow through a much larger laboratory lysimeter.

<u>Falling-head permeameter test</u>. In the falling-head test, a constant pressure head is maintained only at the outflow end

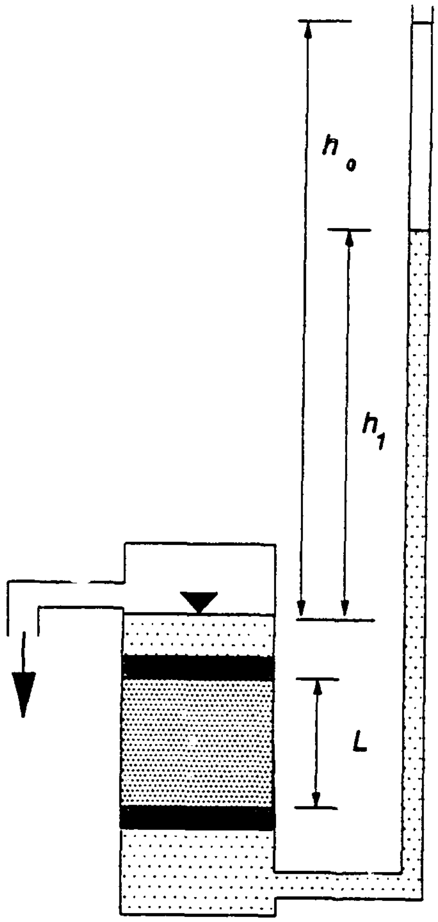

Figure 2-2. Falling Head Permeameter
(source: Domenico and Schwartz, 1990)

of the sample. The head is measured in the standpipe along with the time of measurement (see Figure 2-2). For a sample of length L and a cross-sectional area A, the conductivity is determined by

$$K_s = 2.3 \frac{aL}{A(t_1 - t_0)} \log_{10} \frac{h_0}{h_1} \qquad (2\text{-}5)$$

where a is the cross-sectional area of the stand-pipe and $(t_1 - t_0)$ is the elapsed time for the head to fall from h_0 to h_1 (Freeze and Cherry, 1979).

Oweis et al. (1990) reported a K_s of 1.5 x 10^{-4} cm/sec for samples collected from an active landfill. Details regarding the sample collection and preparation were not provided. However, the density of the permeameter sample was given as 1620 - 2430 lb/yd^3 and the estimated _in situ_ density was 1107 lb/yd^3.

Application of laboratory methods to MSW. Inaccuracies associated with soil permeameter tests are further complicated by MSW samples collected from laboratory lysimeters which only approximate field conditions within a landfill. Difficulties in collecting a truly undisturbed representative sample, and the relative size of the sample are the primary cause of these inaccuracies. If the sample is repacked into the permeameter, the hydraulic conductivity will only approximate the hydraulic conductivity of an undisturbed sample. The sample must be tightly pressed against the sidewalls of the permeameter chamber to ensure that channeling along the sidewalls does not occur (Sowers, 1979). If the medium is heterogeneous with

irregular pores, fissures and stratifications typical of MSW landfills, the small sample size cannot adequately represent the landfill. The small permeameter sample can only represent a minute location within the landfill mass. If the hydraulic gradient in the field is small, as in the case of most landfills, the induced gradient of the constant-head laboratory test will yield non-representative results. The induced gradient of the constant-head laboratory tests are sometimes 10 to 100 times greater than the gradients in the field (Sowers, 1979).

Field Methods

Field tests are much more reliable than laboratory tests because they integrate the effects of discontinuities, irregularities, and the intermediate sand layers typical of landfills. Field tests utilized for the direct measurement of MSW hydraulic conductivity include infiltration tests, open-end borehole tests, and pumping tests.

Infiltration tests. The maximum rate at which water can move in the soil is the potential infiltration rate. This is the rate that will occur when the supply of water at the surface is unlimited, as when the soil is covered by a ponded body of water. The infiltration rate is highest at the beginning of an infiltration event, but decreases as infiltration continues and the wetted zone in the soil expands downward. The infiltration rate may eventually become constant. One of the earliest physical infiltration equations was developed by Green and Ampt (1911, as cited in Bouwer,

1978) and later modified by several authors. By applying Darcy's equation to the wetted zone and assuming vertical flow, uniform moisture content, and constant hydraulic conductivity in the wetted zone, the hydraulic conductivity of the wetted zone is given as

$$K_i = q_s \frac{L_f}{H_w + L_f + S} \tag{2-6}$$

where q_i is the Darcy velocity (L/T), L_f is the depth of the wetting front, H_w is the depth of water above the soil, and S is the capillary suction head at the boundary of the wetting front (see Figure 2-3). The wetting front is an abrupt interface between the wetted and non-wetted material (Bouwer, 1978).

Townsend (1992) performed an extensive investigation of leachate recycle at the Alachua County Southwest Landfill (ACSWL). As part of that effort, the infiltration rate of ponded leachate atop a Class I lined 25-acre landfill unit approximately three years old was determined. The ponds provided a continuous source of leachate for leachate recycle through the landfill matrix. Four ponds were excavated at sizes ranging from 6,000 to 20,000 ft^2 and depths of four to six feet. The volume of leachate infiltrating the landfill from the ponds was determined from weekly water budgets on each pond. Townsend (1992) applied Bear and Zaslavsky's (1968) method for vertical flow through horizontal strata of different hydraulic conductivities. The strata represented

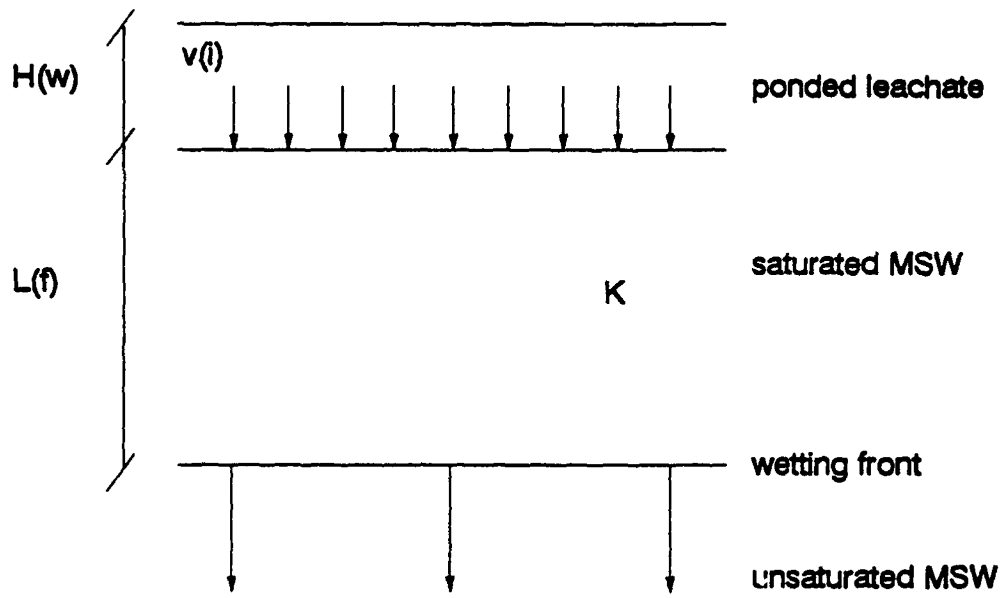

Figure 2-3. Infiltration From a Continuous Source by a Wetting Front (source: Bouwer, 1978)

the bottom layer of the pond: rock (1-inch diameter) or sand ($K > 10^{-3}$ cm/sec), and compacted MSW. The vertical <u>in situ</u> K_v ranged from 5×10^{-6} to 1×10^{-5} cm/sec. The in-place compaction was estimated from aerial topographic surveys to be 1,300 to 1,400 lb/yd^3 (Bruner, 1992, as cited in Townsend, 1992).

Oweis et al. (1990) reported a K_s of 1.1×10^{-3} cm/sec based on an infiltration rate in a test pit. The density of the MSW was estimated at 1080 to 1620 lb/yd^3. Additional information regarding the methodology employed was not provided in the literature.

<u>Open-end borehole tests</u>. The steady state rate at which water added to a well casing or otherwise open borehole with a constant head under gravity flow was used to empirically derive the hydraulic conductivity. The saturated hydraulic conductivity is calculated from the empirical relationship

$$K_s = \frac{Q}{5.5rh} \tag{2-7}$$

where Q is the constant volumetric flow rate at a constant head and under gravity flow conditions, r is the inside radius of the well casing, and h is the differential head necessary to maintain steady state conditions within the well casing (U. S. Bureau of Reclamation, 1960 as cited in Cedergren, 1989). EMCON Associates (1983) used the open-end borehole method as part of their site closure study at the U. S. EPA Boone County experimental landfill. The facility at Boone County, Kentucky included a field scale landfill (149 x 30 x

10 ft) and four smaller test cells which received municipal solid waste from 1970 to 1980. The saturated hydraulic conductivity of the landfill was measured at seven different locations. The depth of the boreholes ranged from 3.3 to 7.0 feet deep. The hydraulic conductivities ranged from 1 x 10^{-2} to 4 x 10^{-2} cm/sec and the average refuse density was measured at 1260 lb/yd^3.

Pumping tests. A conventional method to determine the hydraulic conductivity of a soil formation is the Theis nonequilibrium pumping test method. Analogous to heat flow, the nonequilibrium equation is given as

$$s=\frac{Q}{4\pi T}W(u) \tag{2-8}$$

where s is the drawdown in an observation well, Q is the steady pumping rate, T is the transmissivity, and W(u) is the well function. Transmissivity is defined as

$$T=K_s b \tag{2-9}$$

where K_s is the saturated hydraulic conductivity and b is the saturated thickness of the formation. The well function is defined as the infinite series (2-10)

$$W(u)=0.5772-\ln u+u-\frac{u^2}{2\cdot 2!}+\frac{u^3}{3\cdot 3!}$$

where u is defined as

$$u=\frac{r^2 S}{4Tt} \tag{2-11}$$

and r is the distance from the pumping well to the observation well, t is the duration in which the drawdown occurs, and S is

the storage coefficient. There are numerous field applications of the Theis nonequilibrium equation. The one application found in the literature for the measurement of saturated hydraulic conductivity of MSW is the distance drawdown method (Jacob and Cooper, 1946 as cited in Domenico and Schwartz, 1990).

The distance drawdown method was based on a modified form of the Theis equation

$$s=\frac{Q}{4\pi T}(-0.5772-\ln\frac{r^2S}{4Tt}) \qquad (2-12)$$

Cooper observed that the sum of the infinite series beyond ln u is negligible when u is small (Domenico and Schwartz, 1990). This occurs at large values of time, t, or small distances from the pumping well, r. For drawdown measurements at two locations at the same instant of time, this equation was modified as

$$s_1-s_2=\frac{2.3Q}{4\pi T}\log\frac{r_2^{\,2}}{r_1^{\,2}} \qquad (2-13)$$

where at time t, the drawdown s_1 is at r_1 and the drawdown s_2 is at r_2.

Oweis et al. (1990) determined the saturated hydraulic conductivity from a pumping test at an active, unlined MSW landfill in New Jersey. An array of four wells: one pumping and three monitoring, were installed in an area with an average refuse thickness of 105 feet and an estimated saturated thickness of approximately 30 feet. The pumping well, installed by the cable tool method, had a 6-inch

diameter stainless steel casing and screen assembly installed in a 20-inch borehole filled with 3/8-inch pea gravel. The large diameter gravel pack was selected to maximize hydraulic continuity with the saturated zone of the MSW and to offset anticipated plugging of the screen and gravel pack by small debris of MSW. This measure was rendered ineffective by overpumping during a step-drawdown test. The step-drawdown test was conducted to determine the maximum constant pumping rate with minimal well losses created by turbulent flow of water through the screen and into the pump intake. Observation wells were installed at 28, 71.5 and 199.5 ft from the pumping well with a hollow-stem auger. The observation wells had a 2-inch diameter stainless steel casing with 90 ft of slotted well screen.

Leachate was pumped at a constant rate of 20 gpm for 27.3 hours followed by a monitored recovery period of 2.5 days at which time the leachate level in the pumping well returned to 1.64 ft below the original static level. A second pump test was conducted at 12.5 gpm. The observed values for drawdown were corrected to permit the use of the Jacob straight-line method of analyses for confined aquifers. The transmissivities were 7.86 m^2/day for 12 gpm and 19.6 m^2/day for 20 gpm. Based on an assumed saturated thickness of 30 feet, the calculated saturated hydraulic conductivities were 1 x 10^{-3} and 2.46 x 10^{-3} cm/sec. Oweis et al. (1990) concluded that in the absence of site-specific data, a K_s of 10^{-3} cm/sec

was a reasonable first estimate for typical MSW that has good compaction.

Empirical Models

In addition to the applied methods of MSW K measurements cited in the literature, several values for hydraulic conductivity which have been used to model leachate flow and/or leachate generation are also cited. The saturated hydraulic conductivity is a significant parameter for leachate generation models for the design of landfill liners and leachate collection systems. A brief description of the models and the rationale for the hydraulic conductivity selected is presented below. The models and the values selected to represent the hydraulic conductivity are summarized in Table 2-3.

HELP Model

The Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1984) is a computer model which simulates the hydrologic processes of a landfill by combining daily sequential estimates of vertical and lateral flow within the landfill matrix. The hydrologic inputs include precipitation, evapotranspiration, soil moisture storage, soil moisture potential, unsaturated flow, and vertical and lateral saturated flow. Schroeder et al. (1984) simulated vertical flow by the simultaneous solution of the continuity equation and Darcy's equation. The HELP model default setting for K_s is 1.999×10^{-4} cm/sec. The rationale for this value was not provided in the literature. Schroeder and Peyton (1988)

Table 2-3. Summary of MSW Hydraulic Conductivity Values from Empirical Models

Author(s)	Model	Field Verification	Rationale for Selected K	Hydraulic Conductivity (cm/sec)
Korfiatis et al. (1984)	1-Dimensional unsaturated flow nonsteady state	Laboratory Verification Sensitivity Analysis Demetracopoulos et al. (1986a)	Constant-head Permeameter Test Korfiatis et al. (1986)	1.27E-03
Demetracopoulos et al. (1986b)	Korfiatis et al. (1984) with mass transfer	Not Reported	Not Reported	2.12E-05
Schroeder et al. (1984)	2-Dimensional unsaturated steady state	Peyton and Schroeder (1988)	Not Reported	1.999E-04
Noble and Nair (1990)	FULLFILL, Korfiatis et al. (1984) with modified boundary conditions	Not Reported	Not Reported	1.999E-04 (HELP)
Ahmed et al. (1992)	2-Dimensional nonstedy state	Not Reported	Not Reported	2E-02

conducted a field verification study of the HELP model on seventeen landfill cells at six sites. However, the emphasis of this study was on the lateral drainage of the landfill liner. The internal hydrologic nature of the landfills were not investigated.

Moisture Transport Model

Korfiatis and Demetracopoulos (1986) developed a one-dimensional, finite difference, unsaturated flow model to simulate both a saturated and an unsaturated layer within the landfill. The MSW was treated as a homogeneous, partially saturated porous medium where liquid moves vertically downward. A laboratory lysimeter was used to verify the model. The K_s selected was 1.27 x 10^{-3} cm/sec, a value very close to the results of a constant-head permeameter test previously discussed (Korfiatis et al. 1984). The model adequately predicted the actual cumulative volume of leachate discharged. However, a maximum difference of 25% between actual and predicted discharge rates was measured. Korfiatis et al. (1984) did not provide an explanation for this overestimation. They did, however, conclude that at moisture contents above the field capacity of the MSW (50 - 60%) the hydraulic conductivity was the predominant factor in leachate movement. Likewise, at moisture contents less than field capacity (the top portions of the landfill) the diffusion process is important and may be the predominant factor in leachate movement through the MSW. A field verification of the model was not performed.

Demetracopoulos et al. (1986) used the model of Korfiatis and others (1984) and incorporated terms for mass transfer from the solid to the liquid phase to model leachate concentration and applied a value for K_s of 2.118×10^{-5} cm/sec. The results agreed qualitatively with the work of Pohland (1975). A rationale for the selection of K_s was not provided in the literature.

FULLFILL Model

Noble and Nair (1990) of the Center for Environmental Management at Tufts University developed a one-dimensional, finite-difference computer model for unsaturated flow. The model was similar to the model proposed by Korfiatis et al. (1986). However, the models differed in the treatment of boundary conditions and details of the numerical analysis. The model generated detailed moisture profiles and simulated multiple layers characterized as saturated, unsaturated or partially saturated. The model was applied to a landfill in the Boston area to determine the effects of capillarity on vertical moisture profiles in landfills. The default K_s of the HELP Model, 1.999×10^{-4} cm/sec, was selected for the study. The rationale behind the selection was not provided. At the time of the publication, field verification of the FULLFILL model had not been pursued.

Nonsteady State Model

Ahmed et al. (1992) derived a two dimensional, nonsteady state, finite difference model for the prediction of moisture content within a MSW landfill. The previous work of

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convenient means of estimating the hydraulic conductivity. In some types of groundwater investigations, a large number of point hydraulic conductivities are often more useful than a single value of the hydraulic conductivity obtained from a long-term pumping test at the same cost (Papadopulos et al. 1973).

Slug Test Analysis

Slug test data analysis was pioneered by Hvorslev (1951) and Cooper et al. (1967). Their methods were later modified by such authors as Papadopulos et al. (1973), and Bouwer and Rice (1976). Hvorslev (1951) derived a slug test solution limited to unconfined aquifers with partially penetrating wells screened in the saturated interval of the aquifer (Fetter, 1988). Cooper et al. (1967) derived a solution for confined aquifers with fully penetrating well casings screened over the entire thickness of the formation. Bouwer and Rice (1976) presented a solution applicable to unconfined aquifers with fully or partially penetrating wells which may be partially or completely screened.

Bouwer and Rice (1976) Slug Test Analysis

Bouwer and Rice (1976) modified the Theim equation of steady radial flow to a well to the form

$$Q=2\pi K L_e \frac{y}{\ln(R_e/r_w)} \tag{2-14}$$

where Q is the flow into the well (L^3/T), K is the hydraulic conductivity of the aquifer (L/T), L_e is the length of the well through which water enters (L), and y is the water level

in the well below the static level at time t. The assumptions associated with equation (2-14) are: (1) the drawdown of the water table around the well is negligible, (2) the flow above the water table (capillary fringe) can be ignored, (3) head losses as water enters the well (well losses) are negligible, and (4) the aquifer is homogeneous and isotropic (Bouwer and Rice 1976).

The modified Theim equation can be integrated to yield a linear relationship between drawdown in the well and time

$$K=\frac{r'^{2}_{c}\ln(R_e/r_w)}{2L_e}\frac{1}{t}\ln\frac{y_0}{y_t} \qquad (2\text{-}15)$$

where

r'_c = radius of the well where the rise in the water level (y) is measured

R_e = effective radial distance over which y is dissipated

r_w = radial distance between well center and undisturbed aquifer (r_c plus thickness of gravel envelope or developed zone outside casing)

L_e = height of perforated screen, uncased, or otherwise open section of well through which groundwater enters

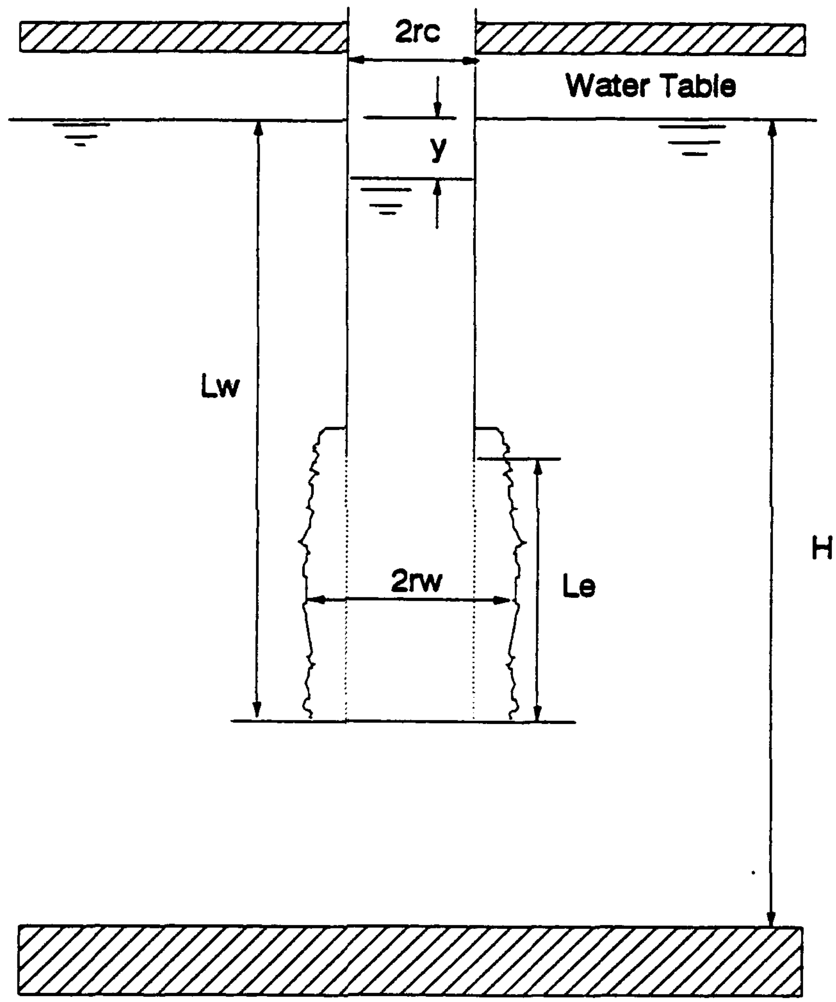
y_o = y at time zero

y_t = y at time t

t = time since y_o

The parameters for the modified Theim equation are illustrated in Figure 2-4.

Since the water level rises in the screened or open section of the well and in the gravel pack, the thickness and porosity of the gravel envelope should be taken into account



(adapted from Bouwer and Rice, 1989)

Figure 2-4. Bouwer and Rice Definition Sketch
(source: Bouwer, 1989)

when determining a value of r'_c for the rising water level in the hydraulic conductivity of the gravel envelope or developed zone is much higher than that of the aquifer. For a gravel pack of porosity n, the equivalent radius of a circle giving this total area can be calculated as

$$r'_c=(\pi r_c^2+\pi(r_w^2-r_c^2)n)^{\frac{1}{2}} \qquad (2\text{-}16)$$

The effective radius, R_e, is the distance from the center of the well over which y is dissipated and depends on the geometry of the flow system. By definition, R_e is the effective value of r_2 in the Theim equation which yields the correct value of Q. Since the Theim equation was developed for horizontal flow, it cannot be used to determine the flowrate, Q(K) for the system illustrated in Figure 2-4. Bouwer and Rice (1976) experimentally determined values of R_e with a resistance network analog for different values of r_w, L_e, L_w, and H. The following empirical equation was developed to relate to R_e the geometry and boundary conditions of the system for partially penetrating wells

$$\ln\frac{R_e}{r_w}=[\frac{1.1}{\ln(L_w/r_w}+\frac{A+B\ln[(H-L_w)/r_w]}{L_e/r_w}]^{-1} \qquad (2\text{-}17)$$

and for fully penetrating wells

$$\ln\frac{R_e}{r_e}=[\frac{1.1}{\ln L_w/r_w}+\frac{C}{L_e/r_w}]^{-1} \qquad (2\text{-}18)$$

where A, B and C are dimensionless parameters shown in relation to L_e/r_w in Figure 2-5.

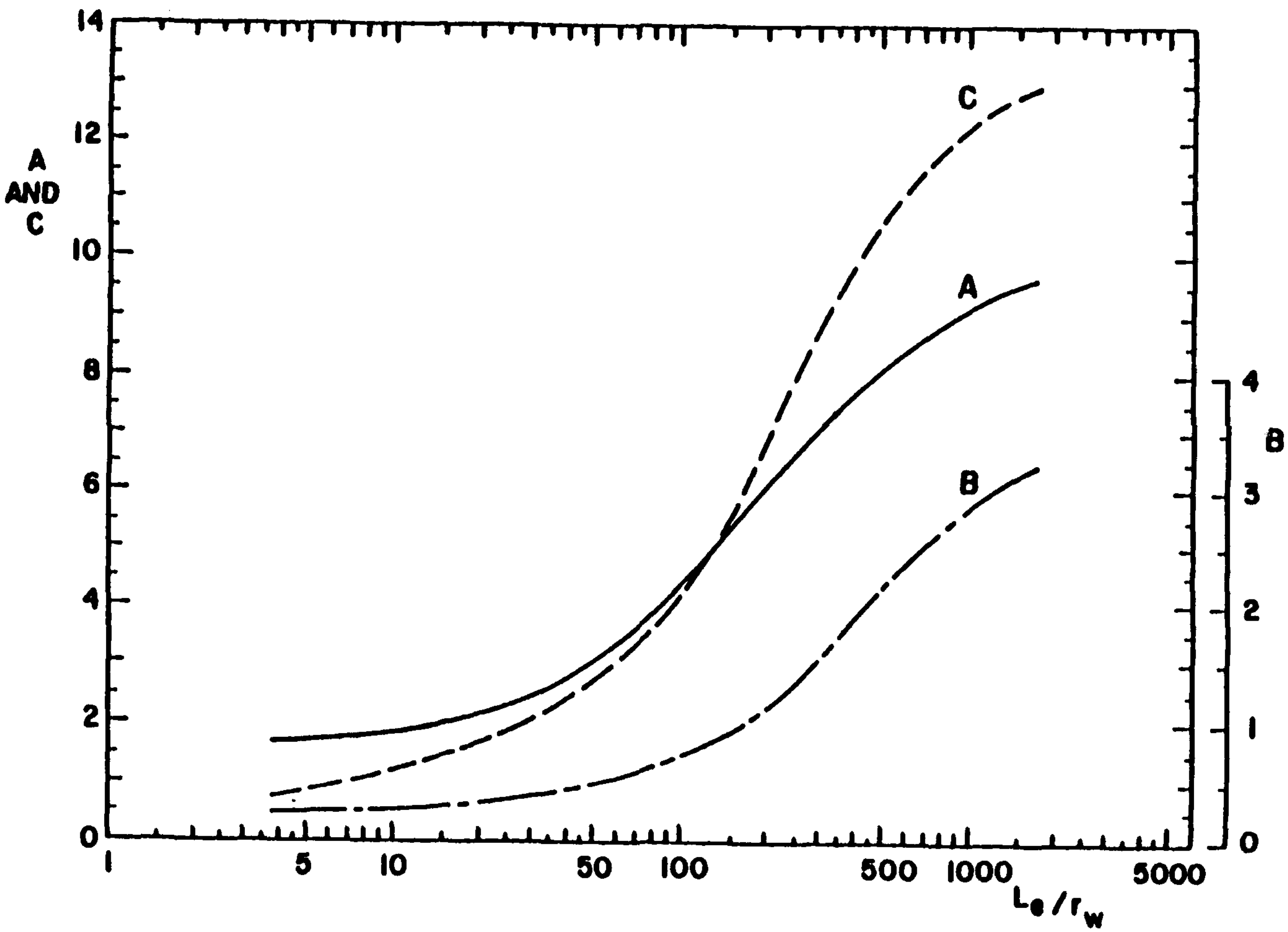


Figure 2-5. Curves Relating Coefficients A, B, and C to L_e/r_w (source: Bouwer, 1978)

The linearity of the Bouwer and Rice (1976) equation for hydraulic conductivity, where K, r'_c, r_w, R_e, and L are constants, allows the determination of hydraulic conductivity from the slope of the best-fitting line of the semilog plot of the field data ln y_t (y-axis) versus t (x-axis)

$$slope=\frac{\ln y_0/y_t}{t} \tag{2-19}$$

and y_0 is the y-intercept of the best-fitting line ($t_0 = 0$) of the early time data.

As stated previously, the Bouwer and Rice (1976) method allows the determination of the hydraulic conductivity of an aquifer near a well. The method is based on the Theim equation and an effective radius, R_e, for the distance over which the head difference between the static water table and the water level in the well is dissipated. The effective radius was derived empirically from an electrical resistance analog and is accurate to within 10-25% depending on how much of the well below the water table is screened or otherwise open (Bouwer and Rice, 1976). The analogs for both fully and partially penetrating wells yield values of ln R_e/r_w that are within 10% of the actual value if the screened length of the well (L_e) is greater than 40% of the length of the well below the water table (L_w) (see Figure 2-4) and within 25% if the screened length of the well (L_e) is much less (for example, 10%) than the length of the well below the water table (L_w).

CHAPTER 3
SITE DESCRIPTION

Site Location

The Alachua County Southwest Landfill (ACSWL) is located on a 232-acre site adjacent to State Road 24 approximately two miles southwest of Archer and fifteen miles southwest of Gainesville, Florida (see Figure 3-1). The surrounding land use is predominantly agricultural. Within a one mile radius of the site boundary, there are also some sand mines, woodlands, and a few residences.

Site Hydrogeology

Geologic Formations

The ACSWL lies on the east side of the Brooksville Ridge. The Brooksville Ridge is a north-south oriented region of sand hills that extends from the western edge of Alachua county southward to Pasco County (CH2M-Hill, 1992a). This overall region is identified as having low relief and ground surface elevations ranging from 65 to 125 feet above mean sea level. The surface features of the site consist of rolling sand hills and depressions.

The soils at the site are predominantly an organic topsoil underlain by strata of fine sand with varying fractions of silt and clay (see Table 3-1). The silt and clay fractions are not continuous beneath the site. They exist as

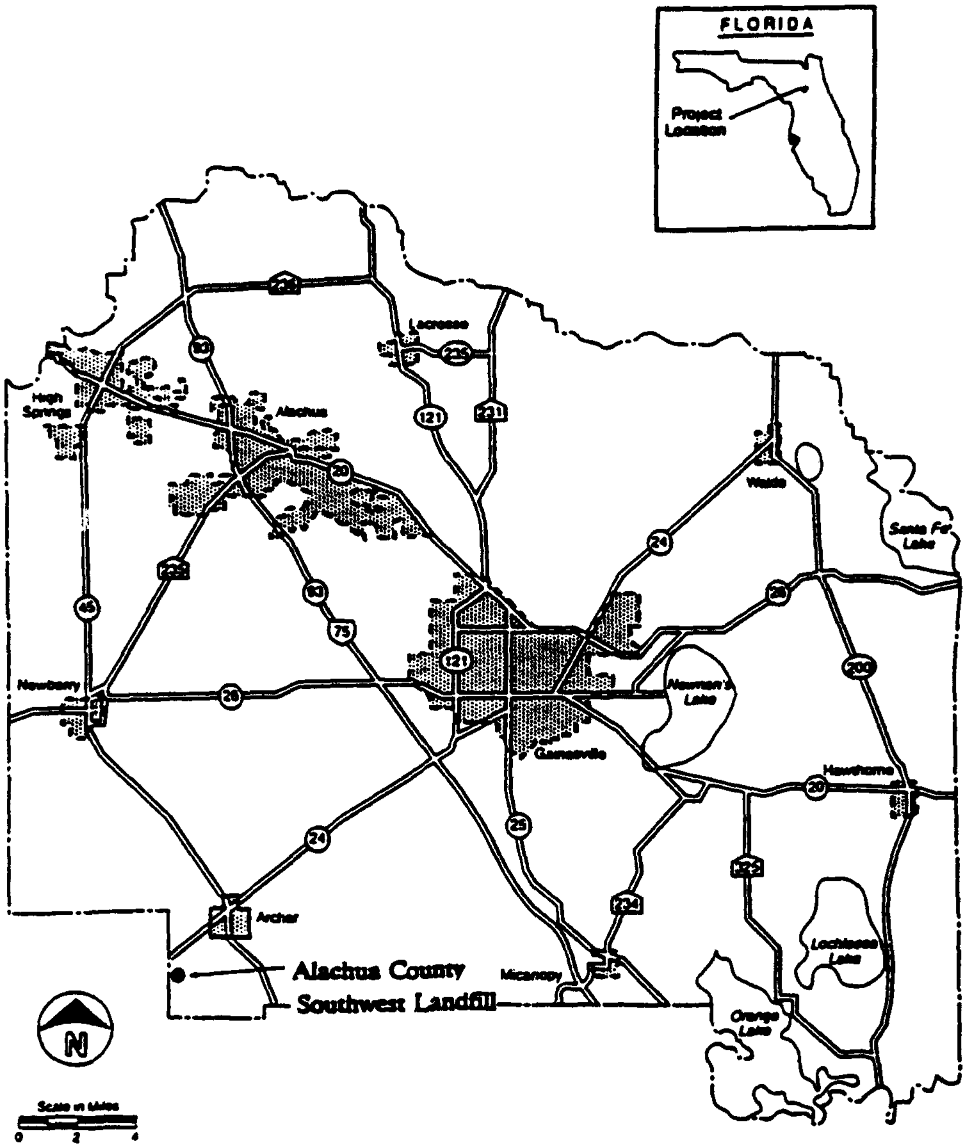


Figure 3-1. Alachua County Southwest Landfill Location
(source: CH2M-Hill, 1992a)

Table 3-1. Summary of Subsurface Conditions at ACSWL

Stratum	Depth to Top (ft)	Depth to Bottom (ft)	Hydraulic Conductivity (cm/sec)
I	0	8.5 - 63.5	4.9 x 10-3-9.8 x 10^{-2}
II	8.5	17.0 - 56.0	3.5 x 10^{-4}-3.5 x 10^{-5}
III	14.0	28.0 - 56.0	7.1 x 10^{-7}-2.8 x 10^{-5}
IV	28.0	30.0 - 91.0	3.9 x 10^{-2}

Stratum	Description
I	sand: fine grained, very loose to very dense
II	sand: fine grained, silty, very loose to very dense
III	sand: fine grained, clayey, loose to medium dense
IV	limestone

(source: CH2M-Hill, 1992a)

large pockets or lenses between the overburden and the underlying limestone, and are relatively ineffective as a confining layer for the underlying aquifer (CH2M-Hill and ESE, 1986).

The Ocala Limestone formation immediately underlies these soils at elevations of 25 to 55 feet above mean sea level. Ocala Limestone is a soft, white, chalky, coquina limestone that forms the upper unit of the Floridan Aquifer, which is the primary source of groundwater in the area. The estimated thickness of the upper unit of the Floridan Aquifer in the vicinity of the landfill is approximately 200 feet.

Shallow Ground Water

All subsurface investigations to date indicate that no permanent shallow groundwater exists at the site. All surface water occurs as temporary ponding resulting from precipitation. Water levels measured in shallow wells and wells penetrating the limestone of the Floridan Aquifer show little or no difference indicating that a confining unit is not present.

The Floridan Aquifer

The Floridan Aquifer is the only source of groundwater in the area. The estimated hydraulic conductivity of the aquifer at the site is 3.9×10^{-2} cm/sec (110 ft/day) based on an estimated aquifer thickness of 200 feet and aquifer porosity of 20% (Sproul 1986 as cited in CH2M-Hill and ESE, 1986). Based on this estimate and a potentiometric gradient of 0.00023 feet/feet, the average groundwater velocity at the

site is estimated to be 4.65 x 10^{-5} cm/sec (CH2M-Hill and ESE, 1986). This value is not representative of the actual groundwater velocity of the Floridan aquifer as a result of the nature of groundwater flow in limestone along solution-enlarged joints, fractures, and bedding planes rather than through the pores of the rock. Actual groundwater flow velocity is estimated to be in the range of 1 to 3 ft/day (3.5 x 10^{-4} - 1.1 x 10^{-3} cm/sec) (CH2M-Hill and ESE, 1986).

Direction of Groundwater Flow

The regional potentiometric surfaces in Alachua County for both wet and dry seasons are shown in (See Figures 3-2 and 3-3). Groundwater flow direction at the site is northeasterly and, over the region, is controlled by topography and the localized recharge in the area of the Brooksville Ridge. Recharge in this area produces a groundwater mound in extreme southwestern Alachua county. This potentiometric high is the cause of the observed northeastward flow of groundwater at the site. This northeastward direction of flow continues for some distance beyond the landfill before converging with the regional groundwater flow toward the northwest.

Site History

Landfilling operations at the site began in late 1973 and at that time there were two other landfilling operations in the county. Presently, ACSWL is the only solid waste disposal facility in Alachua county, and it is projected to meet the county's disposal needs through 1999. Siting for a new landfill is in progress during 1992-93.

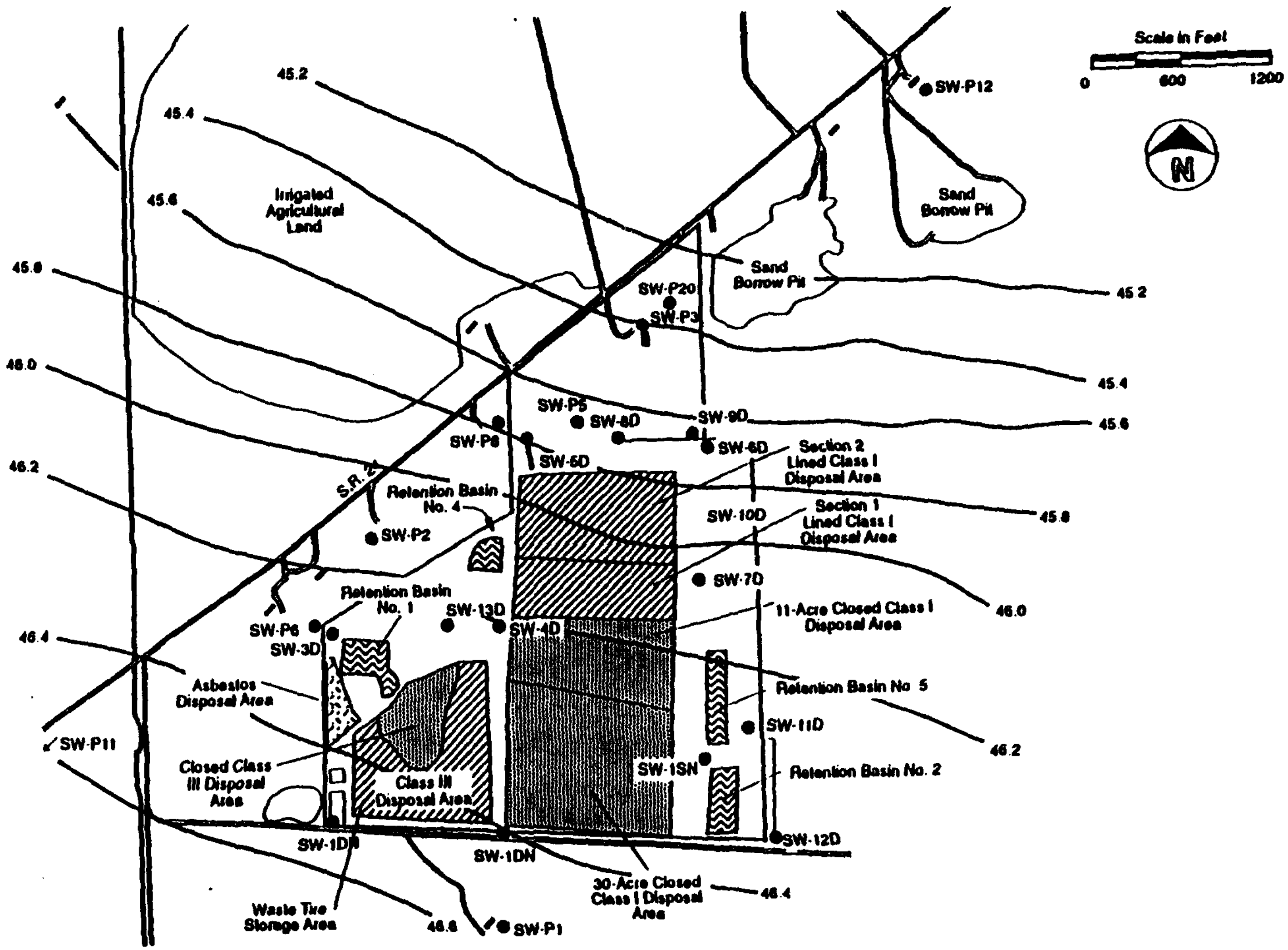


Figure 3-2. Potentiometric Surface at ACSWL, Floridan Aquifer, January 1991

(source: CH2M-Hill, 1992a)

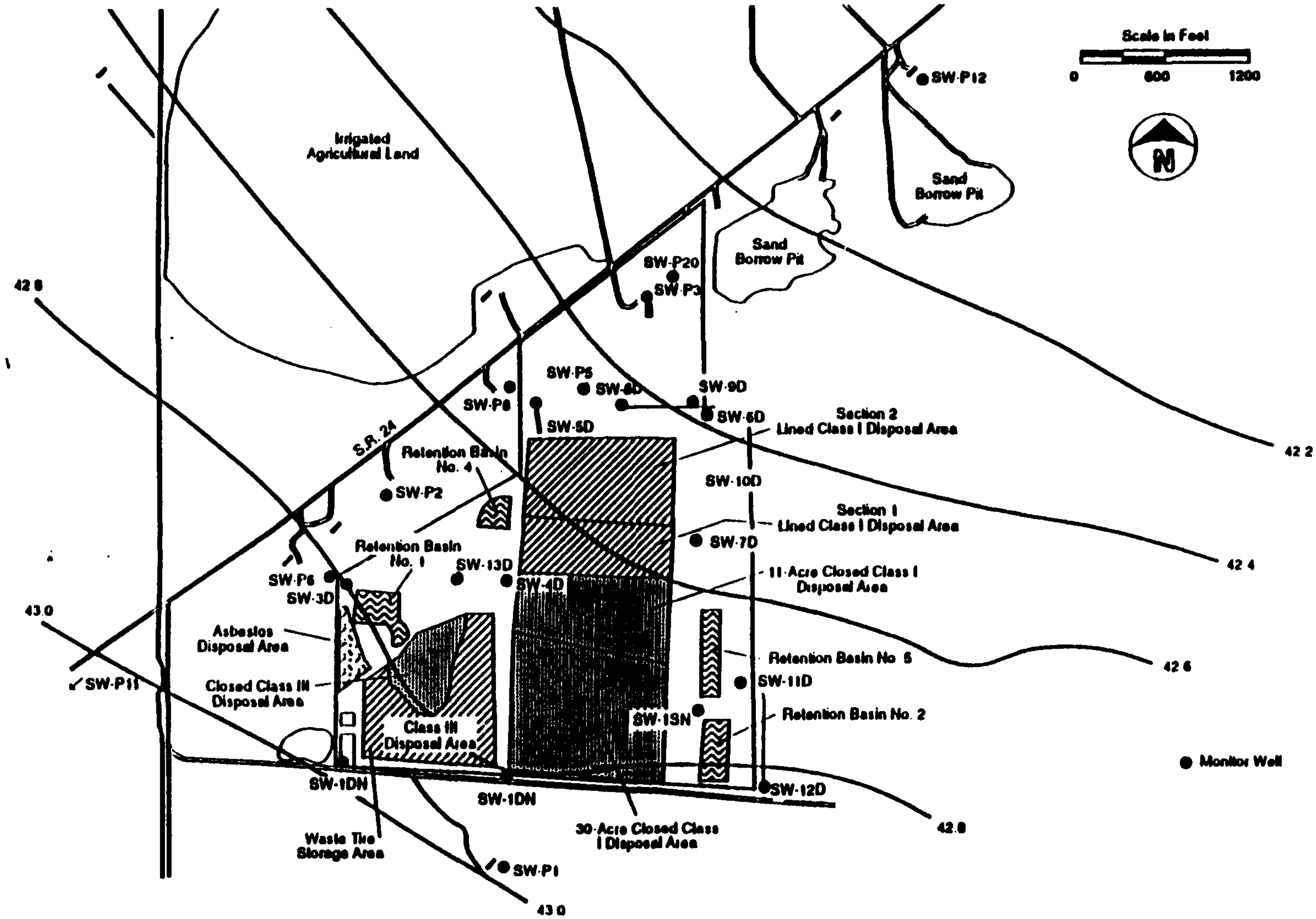


Figure 3-3. Potentiometric Surface at ACSWL, Floridan Aquifer, July 1991
(source: CH2M-Hill, 1992a)

The site is comprised of a number of separate landfill units (See Figure 3-4). Municipal solid waste (MSW) occupies three separate units: two closed unlined units, and one lined unit which has not reached full capacity. The oldest of the three units, a 30-acre unit, received MSW from November 1973 until December 1985 when it was closed and capped. The second unlined unit, an 11-acre unit, received MSW from December 1985 until May 1988 when it was closed and capped. The lined cell, the current disposal unit, is a composite-lined Class I landfill equipped with a leachate collection system. The unlined 30-acre and 11-acre units are the focus of this research.

<u>The 30-acre Unlined Unit</u>

The 30-acre unit was designed for the modified open end area method of landfilling. This method involves the excavation of a large cell in which MSW is placed. Then, as the fill progresses along one face of the unit, excavation proceeds along the opposite face and the excavated material provides cover material. During initial excavation, soil slopes are typically 3:1 with the bottom of the excavation sloped to drain to the middle. The MSW is placed in no greater than 2-foot thick layers and compacted by at least three to five passes of a compactor. The berms of the 30-acre unit allowed an average depth of 49 feet of total fill (Darabi 1983a as cited in CH2M Hill and ESE, 1986).

Samples from regularly scheduled ground water quality monitoring in 1985 suggested groundwater contamination in the

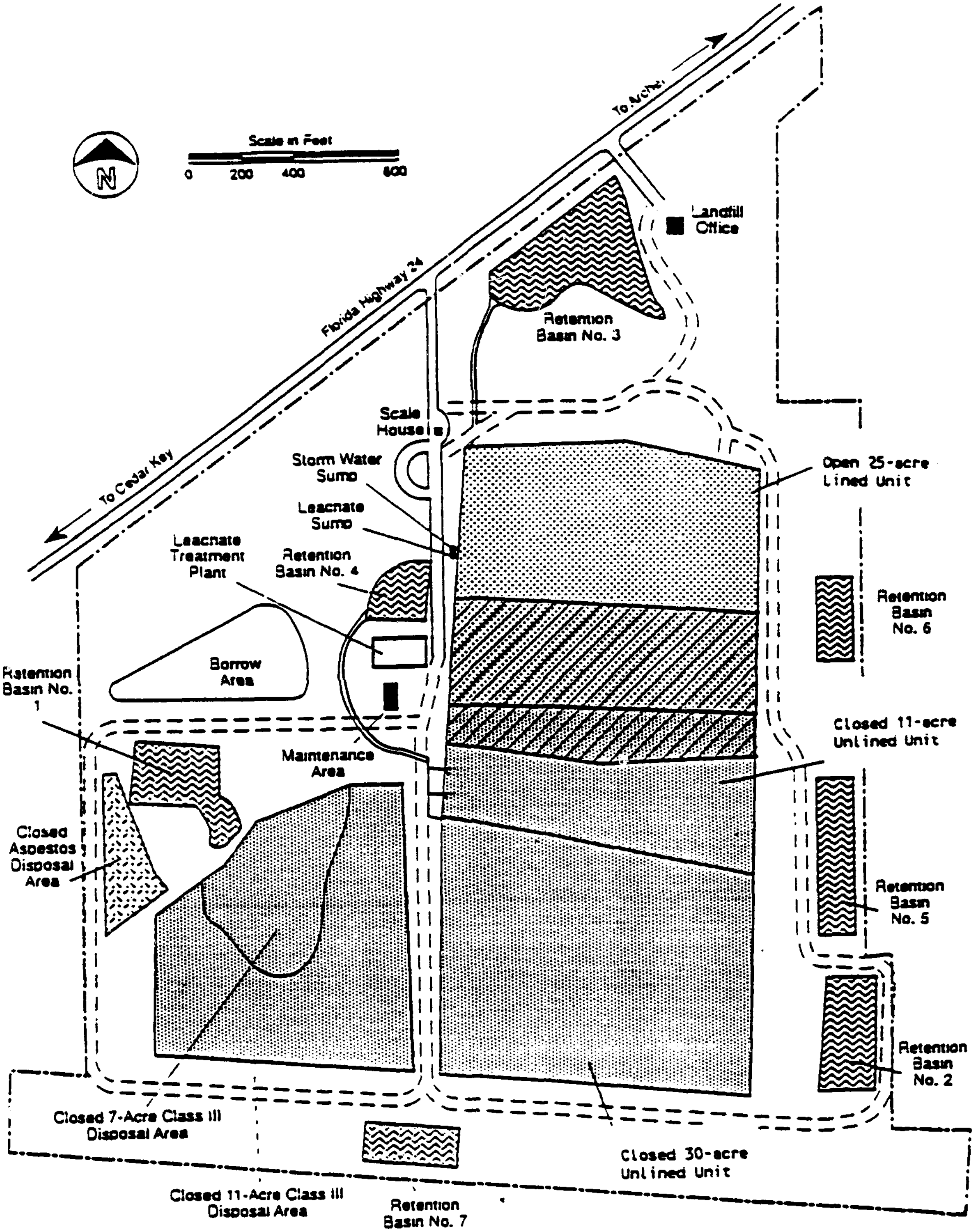


Figure 3-4. Alachua County Southwest Landfill Units
(source: CH2M-Hill, 1992a)

vicinity of the site. Further groundwater sampling not only confirmed the suspected contamination, but also indicated that two contaminant plumes existed at the site and extended to the north and east beyond the landfill boundaries. Both of the plumes were at least in part the result of the 30-acre unlined landfill unit. One plume contained chlorinated organics and the other contained high levels of total dissolved solids, ammonia, and purgeable aromatic compounds (CH2M Hill, 1988).

In 1986, the Florida Department of Environmental Regulation (FDER) issued a Consent Order to Alachua County requiring among several items that as much of the landfill as possible be covered with an impermeable cap to reduce percolation of rain water into the cell. At that time, 30-acres of the unit were available for cover. During the construction of the composite liner of the 25-acre lined cell in 1987, the cover system for the 30-acre unit was completed and vertical gas vents were installed to protect the cover system from potential damage and to prevent methane migration. In the meantime, the adjacent 11-acre unit remained the active unit and landfilling proceeded towards the north.

Unfortunately, there is no documentation of the quantity or the composition of the waste deposited in the 30-acre unit. Given the estimated depth of 50 feet (CH2M Hill, 1988) and a density of 415 pounds per cubic yard (ESE 1979 as cited in CH2M-Hill, 1988) there are 1.86 million cubic yards or approximately half a million tons of MSW deposited in the unlined 30-acre unit. Information regarding the composition

of the solid waste deposited in the 30-acre unit is limited to three reported occurrences of potentially hazardous wastes deposited before RCRA regulations governing landfills were established. In 1978, an abandoned and ruptured 55-gallon barrel of 70% hydrofluoric acid found in a Minit-Market dumpster was deposited in the southwest corner of the 30-acre site. While a firetruck continuously sprayed the barrel with water to dilute the acid, a front-end loader dumped two bucket loads of lime on the barrel to neutralize the acid, followed by a cover layer of soil (Ferland 1978 as cited in CH2M-Hill and ESE, 1986). The following year, several unsealed barrels were found in retention basin No. 1 (see Figure 3-4) along with grease trap sludge and bulky waste. The exact chemical contents of the barrels were unknown, but analyses of the waste and soil samples indicated the presence of uracil and 5-fluorouracil. The barrels were removed and landfilled at a regulated hazardous waste landfill, but the contaminated grease trap sludge and bulky wastes were excavated and landfilled in the 30-acre unit (Darabi, 1983 as cited in CH2M-Hill and ESE, 1986). In 1985 a leaking drum of unsolidified epoxy resin from Bear Archery was removed from the 30-acre unit. At that time, disposal of hardened epoxy resin was a common practice and was not considered a hazardous waste by FDER (Burke 1985 as cited in CH2M Hill and ESE, 1986).

The 11-acre Unlined Unit

As a result of construction delays and the continuous demand for landfill capacity, Alachua County was authorized by

FDER to raise the final grade of the 11-acre unlined unit by eight feet and reduce the cover system design installed on the 30-acre unit by one foot. This modification provided for a total increase in landfill height of nine feet above the final grade of the 11-acre unit. The finished height of the 25-acre lined unit will also be the higher finished elevation of the 11-acre unlined unit (CH2M Hill and ESE, 1986).

In 1988, gas vents very similar in construction to the 30-acre gas vents were installed. In 1991, source control of the groundwater contamination was complete when the final cover for the 11-acre unit was constructed.

As with the 30-acre unit, detailed information regarding the composition of the waste in the 11-acre site is not available. The results of a waste characterization study for 1985 through 1986 for the 11-acre unit are presented in Table 3-2. Unlike the 30-acre unit, waste items such as tires and construction debris were deposited in separate landfill units.

In July 1992, the gas vents of both the 11-acre and the 30-acre units were slightly modified to accommodate a gas collection system installed to reduce the odors associated with landfill gas. By November of 1992, the gas collection system was in operation. The condensate from the gas manifold is pumped to the equalization tanks at the leachate pretreatment plant for treatment by recirculation into the lined unit or lime precipitation.

Table 3-2. Municipal Solid Waste Characterization Data for 11-acre Unlined Unit

Waste Category	Volume of Waste (tons) 1985	1986
Garbage	26,532	27,378
Brush	448	862
Liquid Waste	532	20
Tires[1]	40	40
Construction Debris[1]	6,053	8,763
Trash	1,279	1,362
Collection Centers	710	834
Road Department[1]	445	192
Total	36,039	39,951

1Deposited in other designated landfill units and not in the 11-acre unit

(source: Hamilton 1986 as cited in CH2M-Hill, 1989)

Construction Details of the 30-acre and 11-acre Gas Vents

The 30-acre Unlined Unit

The method by which the gas vents were installed is not known (Bruner, 1992). Thirty-five gas vents were installed inside 24-inch diameter boreholes. According to the record drawings, the depth of the boreholes ranged from 28 to 35 feet from the bottom of the clay layer of the cover system (see Figure 3-5) with an average depth of 35 feet (CH2M-Hill, 1992b). The well casings were constructed of 4-inch and 6-inch sections of schedule 40 PVC. The construction details are noted in Figure 3-6.

The length of the perforated 6-inch PVC section was twenty feet for all of the gas vents. However, there are three variations for the last 15-foot section of the 4-inch PVC segment: the full length is perforated, the bottom has hand sawed perforations, or the full length is non-perforated (see Table 3-3).

The 11-acre Unlined Unit

As with the 30-acre unit, the method by which the gas vents were installed is not documented (Bruner, 1992). Fifteen gas vents were installed inside 24-inch diameter boreholes. The depth of the boreholes ranged from 26 to 71 ft from beneath the cover system with an average depth of 53 ft (CH2M-Hill, 1992b). As with the 30-acre unit, the well casings are constructed of 4-inch and 6-inch sections of schedule 40 PVC. The construction details for a typical 11-acre gas vent are noted in Figure 3-7. The length of the

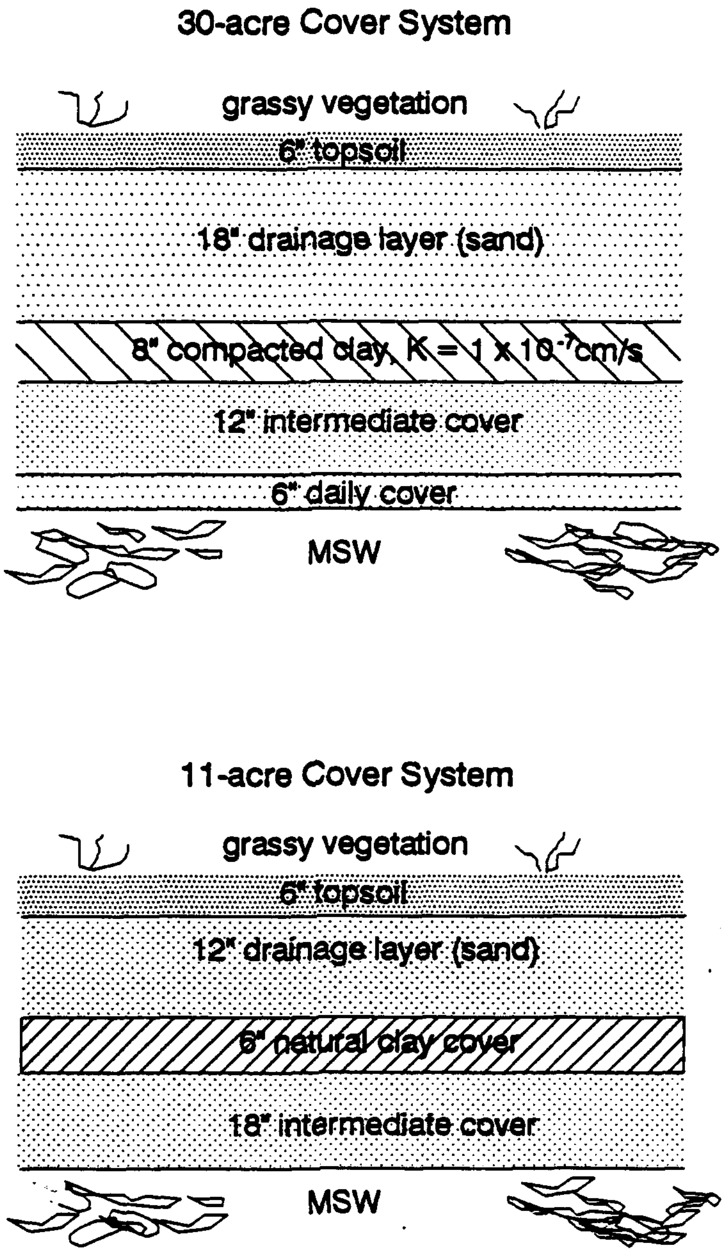


Figure 3-5. Cover Systems for the 30-acre and 11-acre Units (adapted from CH2M-Hill, 1992b)

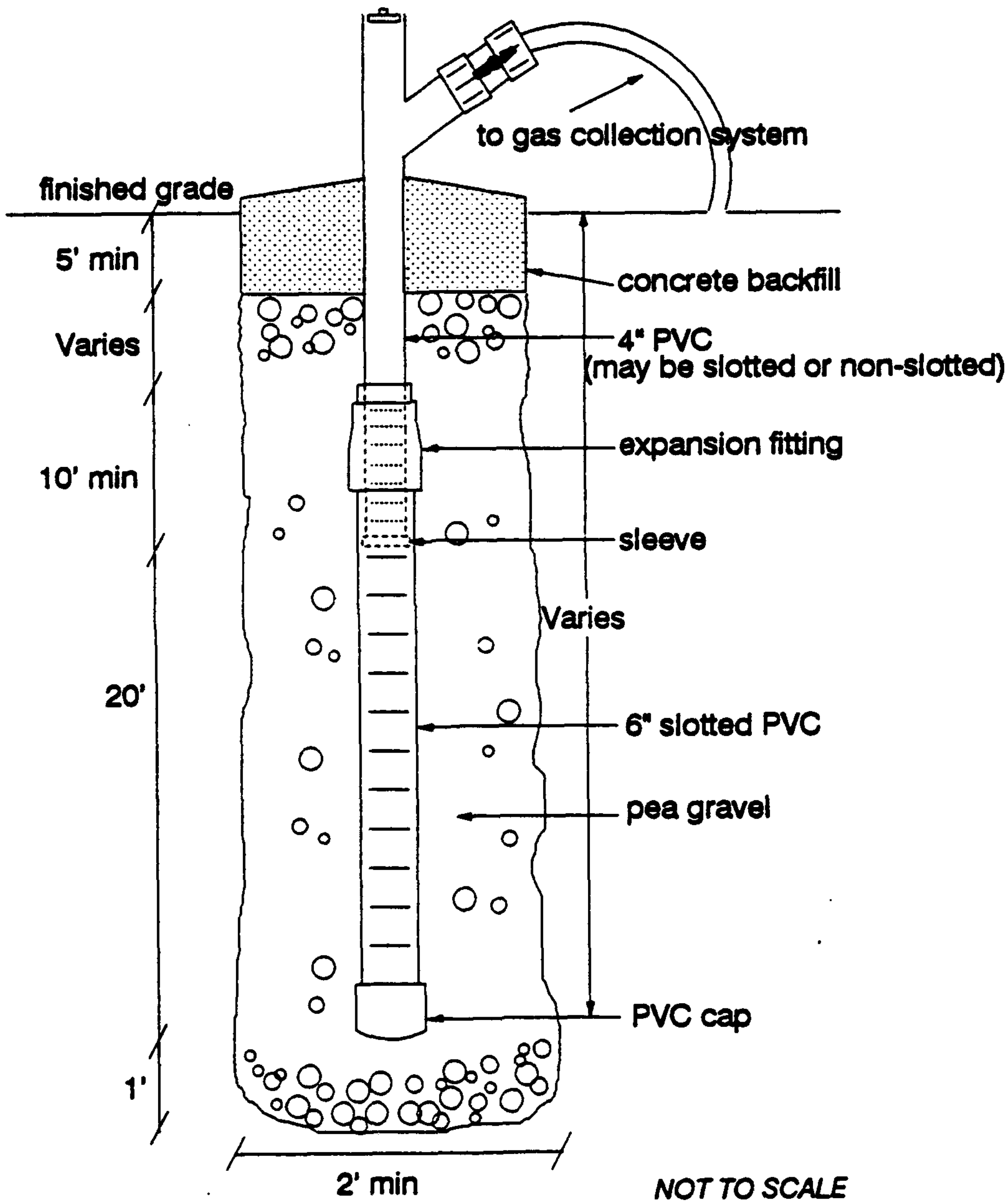


Figure 3-6. Typical 30-acre Gas Vent
(adapted from CH2M-Hill, 1992a)

Table 3-3. Construction Details of the 30-acre Unit Gas Vents

Gas Vent #	Depth Below Clay Cover (ft)	Description of Bottom 4 in. PVC Section
1	35	slotted
2	34	slotted
3	34	slotted
4	35	slotted
5	35	slotted
6	35	slotted
7	34	slotted
8	35	slotted
9	28	non-slotted
10	35	slotted
11	34	slotted
12	34	slotted
13	35	slotted
14	34	slotted
15	35	slotted
16	35	slotted
17	35	slotted
18	35	slotted
19	35	slotted
20	35	hand sawed slots on bottom
21	35	hand sawed slots on bottom
22	31	slotted
23	35	non-slotted
24	35	slotted
25	35	hand sawed slots on bottom
26	35	hand sawed slots on bottom
27	34	slotted
28	35	slotted
29	35	hand sawed slots on bottom
30	35	slotted
31	35	hand sawed slots on bottom
32	35	hand sawed slots on bottom
33	35	slotted
35	29	slotted
42	35	hand sawed slots on bottom

(source: CH2M-Hill, 1992b)

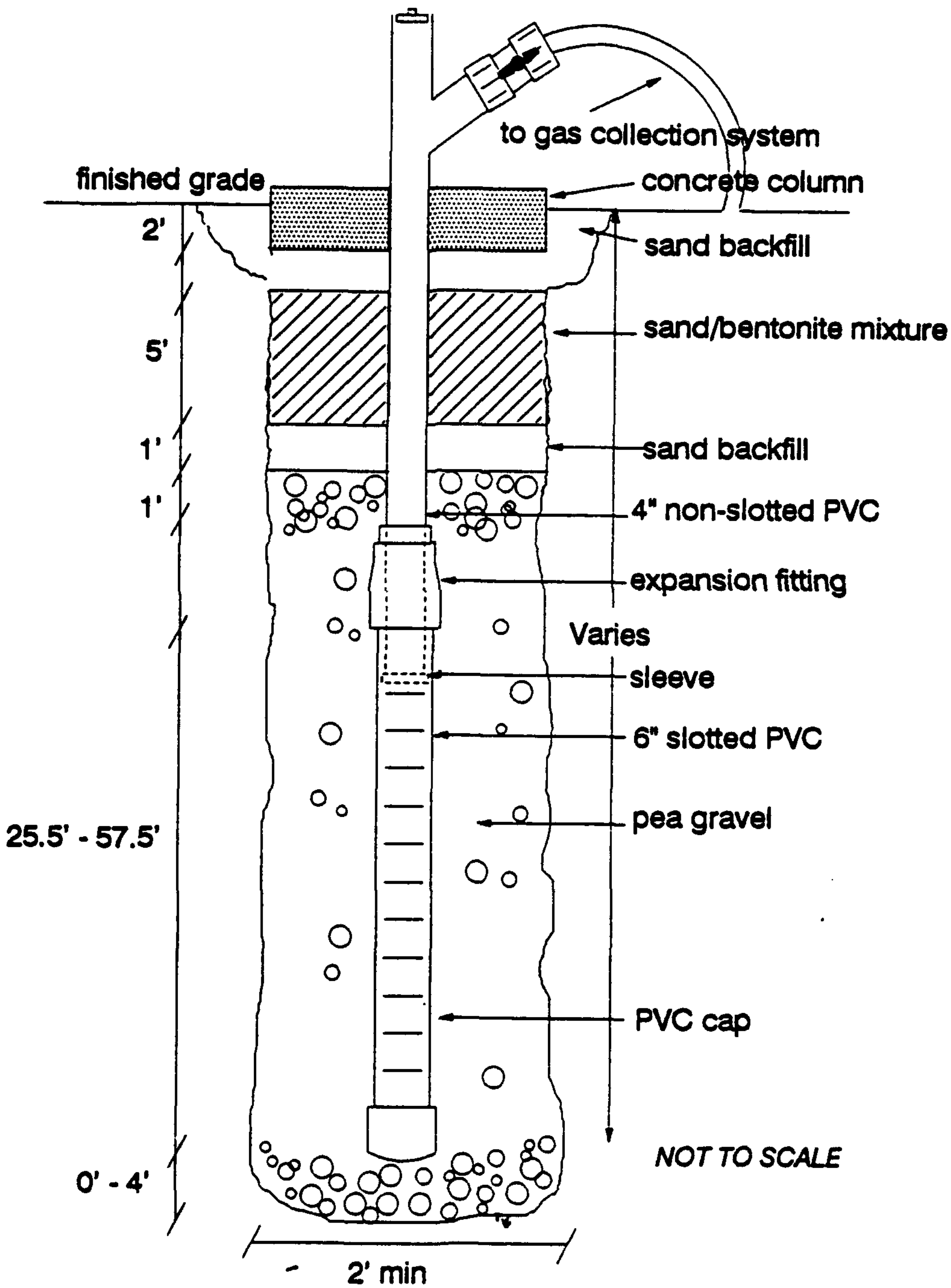


Figure 3-7. Typical 11-acre Unit Gas Vent
(adapted from CH2M-Hill, 1992a)

perforated 6-inch PVC section varied from 25.5 to 57.5 ft with an average length of 48 ft (see Table 3-4). Unlike the 30-acre unit, none of the 4-inch PVC sections were perforated. A complete layout of the gas vents of the 11-acre and the 30-acre units is provided in Figure 3-8. The gas vents shown in Figure 3-8 only represent the vertical gas vents. Where the gas vent numbers are not sequential, the northernmost row of the 11-acre unit in particular, the gas vents not shown are lateral gas vents.

Table 3-7. Construction Details of the 11-acre Unit Gas Vents

Gas Vent #	Depth (ft)	Borehole Depth (ft)	Overdrill Length (ft)	Length of 4 inch Slotted Section (ft)
34	63	60	2	47.5
36	50	46	2	33.5
37	63	63	2	50.5
38	60	54	2	41.5
39	70	71	3	57.5
40	70	64	2	57.5
41	60	50	2	37.5
43	60	54	4	39.5
44	50	36	0	25.5
46	60	53	2	40.5
48	60	56	2	43.5
50	60	60	2	47.5
52	60	61	3	47.5
54	63	63	2	50.5
56	50	46	2	33.5

(source: CH2M-Hill, 1992b)

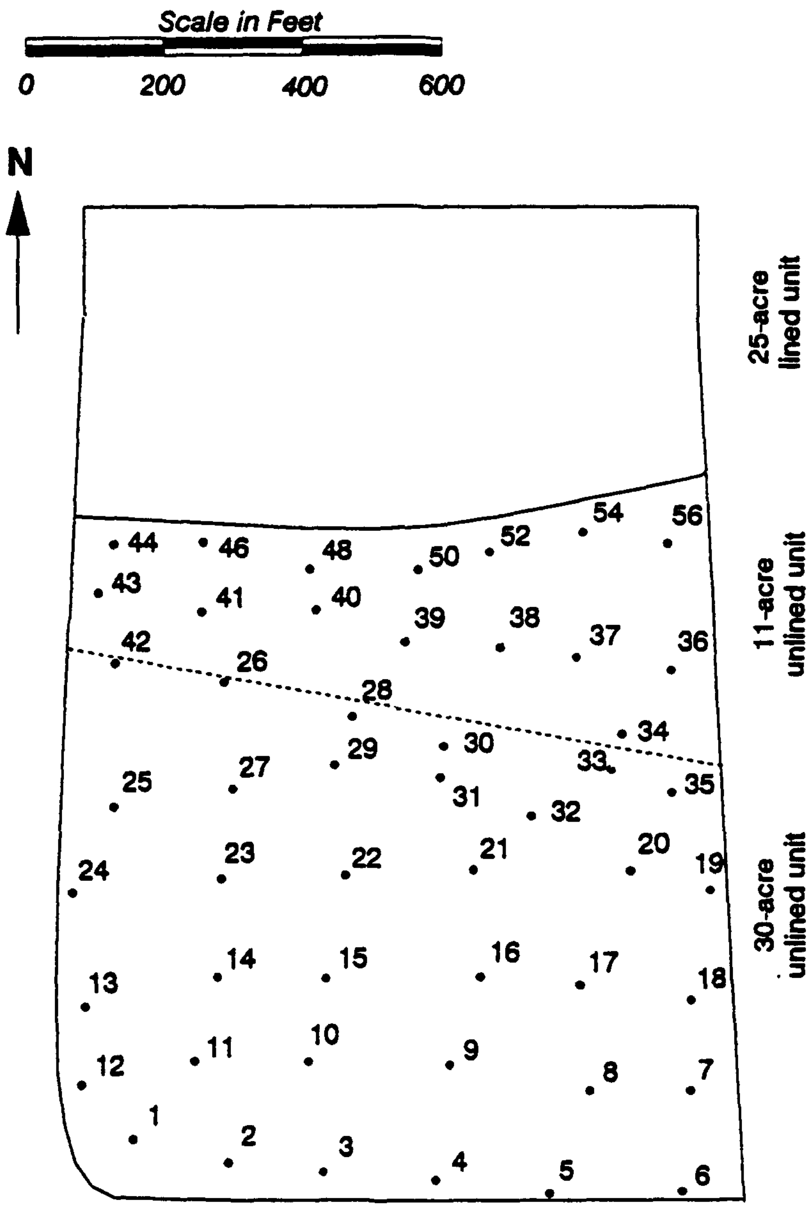


Figure 3-8. Gas Vent Layout for the 30-acre and the 11-acre Units

CHAPTER 4
METHODS AND MATERIALS

Two variations of the slug test were applied at the ACSWL: slug tests with a slug constructed of capped PVC sections filled with sand, and slug tests with the instantaneous removal of a "slug" of leachate by a submersible pump. Before the slug tests were conducted, gas vents were selected on the basis of a history of leachate levels in the gas vents and the condition of the gas vents. A description of the measurements, field equipment, and methods is presented here.

Selection of Gas Vents

Selection of the gas vents for the slug tests was based on a history of leachate level measurements and the condition of the gas vents. Ultimately, slug tests with a slug constructed of PVC piping were conducted in gas vents #8, #20, #21, #22, #26, #30, and #33, and slug tests with a submersible pump were conducted in gas vents #8, #20, and #33. All of these gas vents were in the 30-acre unit.

Leachate Level Measurements

The leachate levels in the gas vents were monitored on a monthly basis with an electric tape. Occasionally the electric tape gave false or intermittent readings as a result of the condensate which accumulated on the sidewalls of the

gas vents. When measurements were inconsistent with the history of leachate level measurements for a particular gas vent, several measurements were made to confirm the results. Later in the study, a weighted stainless steel tape was also used to measure the depth of the leachate. The combination of the two measuring devices and the history of leachate level measurements provided an accurate means to measure the leachate levels in the gas vents.

The depth to the bottom of the gas vent and the depth to the leachate were both recorded as a means to determine the depth of the leachate. Some of the gas vents in the 11-acre unit had a wide variation in measurements for the depth to the bottom of the gas vent indicating the likelihood of partial obstructions (gas vents #40, #41, #43, #44, #46, #48). These gas vents also contained some of the highest leachate levels for the 11-acre unit. Neither the precise location nor the nature of the obstructions could be discerned from the lightweight electric tape. The electric tape had a plastic twin-wire tape with an 8-inch stainless steel 1/2-inch diameter probe. Capped 12-inch sections of stainless steel pipes one and two inches in diameter were also lowered into the 11-acre gas vents to locate the obstructions and identify the nature of the obstructions. The precise location and the nature of the obstructions were still not discernible and additional measures were necessary to determine the condition of the gas vents and the possibility of conducting a slug test with a PVC slug or a submersible pump.

Condition of the Gas Vents

Gas vents #40, #41, #43, #44, #46, and #48 on the west side of the 11-acre unit, where the variability in the measurements was most prevalent, were examined with a "mini" video camera provided by Gainesville Regional Utilities. The results of the viewing clearly indicated that the nature of the obstruction was the well casing itself. Some of the gas vents had collapsed in the perforated section of the well casing under the vertical stress of the landfill. All of the gas vents from the 30-acre and 11-acre unlined units and the 25-acre lined unit were subsequently video taped by a contractor. In some cases, the results of the contractor's written report and video tape were inconclusive for the 30-acre unit and contradicted the history of measurements for the 11-acre unit. An extensive field verification of the contractor's work was conducted. The history of leachate levels in the gas vents and the transcript and field notes for the video surveys are provided in Appendix A.

The results of the video and the history of leachate measurements were used to select the optimum gas vents for the slug tests. Gas vents with the highest leachate levels and which appeared to be free of obstructions were selected for the PVC slug tests. These same gas vents were also selected for the pump slug test, but some were eliminated in the field as a result of difficulties in lowering the pump into the gas vents.

Slug Tests

PVC Slug Tests

Slug tests with a PVC slug constructed from a capped 8-foot section of 3-inch schedule 40 PVC partially filled with sand, were conducted in gas vents #8, #20, #21, #22, #26, #30, and #33. The rate of change of the leachate levels in the gas vents was measured for both slug injection and slug withdrawal.

Equipment. An Envirolab datalogger and transducers were provided by CH2M-Hill of Gainesville, Florida. The data loggers were programmed to take readings at 1-second intervals for the first minute followed by 20-second intervals for the next three minutes, and 30-second intervals for the last five minutes.

Procedure. On the same day as the PVC slug test, the leachate in the gas vent was measured with a weighted steel tape three times to establish the static leachate depth in the gas vent prior to placement of the transducer. These measurements were compared with all previous measurements for that particular gas vent and checked for inconsistencies. The depth to the bottom of the gas vent was also measured to determine the maximum depth available to lower the slug and ensure it was completely submersed in the leachate.

The pressure transducer was lowered into the gas vent first, and the cable was secured to the outside of the well casing with duct tape. Then, the PVC slug was lowered to a point just above the surface of the leachate. The leachate

level in the gas vent was monitored with the datalogger. When the leachate level stabilized, the PVC slug was released to a point just above the bottom of the gas vent (slug "in") and the datalogger recorded the leachate levels in the gas vents at the programmed time intervals. Once the leachate in the gas vent recovered to the original static level, the PVC slug was instantaneously removed for second slug test (slug "out") in that same gas vent. Two people were required to remove the slug (hand-over-hand) as quickly as possible. The slug immersed weighed approximately 25 pounds.

<u>Pump Slug Tests</u>

Slug tests with the instantaneous removal of a slug of leachate by a submersible pump were conducted in gas vents #8, #20, and #33. The number of gas vents available for this type of slug test were limited by the size of the pump. The combined effect of the 4-inch to 6-inch transition and the non-vertical nature of the gas vents restricted passage of the pump, 3.875 inches in diameter and 29.5 inches long, in all but three of the gas vents selected for the PVC pipe slug tests (#8, #20, and #33).

<u>Equipment</u>. A Goulds 1 HP submersible pump was used for the slug test. Two eyelets were welded on opposing sides of the discharge and check-valve assembly of the pump. The eyelets not only provided a means of harnessing the pump with aircraft cable, but more importantly the opposing eyelets provided a means of lowering and retrieving the pump, which weighed approximately 60 pounds, in a plumb position, and

the maneuverability of the pump. These precautions were necessary as a result of the construction and condition of the gas vents. The transition between the 4-inch PVC section and the 6-inch PVC section provided a means to lodge long and heavy items which were not plumb. Although the gas vents selected for slug tests were in good condition based on the video and history of field measurements, the video indicated that all of the gas vent schedule 40 PVC well casings had a slight curvature.

A Global PT datalogger with 10 psi transducers, and a Hewlett Packard laptop computer were provided by Jones Edmunds & Associates, Inc. of Gainesville, Florida. The default setting of the datalogger was 13.65 seconds. A hand-held push button switch was utilized for additional readings at 1-second intervals. Measurements at 1-second intervals and the default measurements at intervals every 13.65 seconds were recorded when the switch was pressed at 1-second intervals.

A Honda EX5500 generator was provided by the ACSWL staff. Power connections to the pump were provided by means of a portable electrical panel shown in Figure 4-1.

A Warrick liquid level control system was installed in series with the pump controls to prevent the pump from completely evacuating the gas vent. Precautions were necessary to ensure that the pump would not pump "dry" and generate heat from friction in the presence of combustible gases typical of MSW landfills. The components of the liquid level control system included four Teflon™ series 3Y Warrick

electrodes with cables and an intrinsically safe sensing circuit. The four electrodes and cables were paired in lengths of 40 and 60 feet. One of the short electrodes was designated as the "high" electrode and one of the long electrodes was designated as the "low" electrode. The remaining electrode of each pair was designated as a reference electrode (see Figure 4-1). The Warrick 230V intrinsically safe control is normally open. Therefore, at the start of the slug test, all four electrodes were immersed in the leachate: the "high" pair just below the static leachate level and the "low" pair just above the pump intake. When the "low" electrodes were no longer submersed, the pump shut off. The ACSWL staff provided the use of their water wagon and weigh station. The water wagon was used to collect and weigh the pumped leachate at the weigh station to determine the volume pumped from the gas vents. The pumped leachate was ultimately discharged in the infiltration ponds of the 25-acre lined unit.

Procedure. The day before the slug tests, the transducers and the datalogger were calibrated to atmospheric pressure. A capped PVC pipe of known height was filled with water. The transducer was then lowered to the bottom of the pipe and the voltage was recorded on the datalogger. The day of the slug test, the static depth of the leachate was measured with a weighted steel tape three times to establish the static leachate depth in the gas vent prior to placement of the pump and the depth to the bottom of the gas vents.

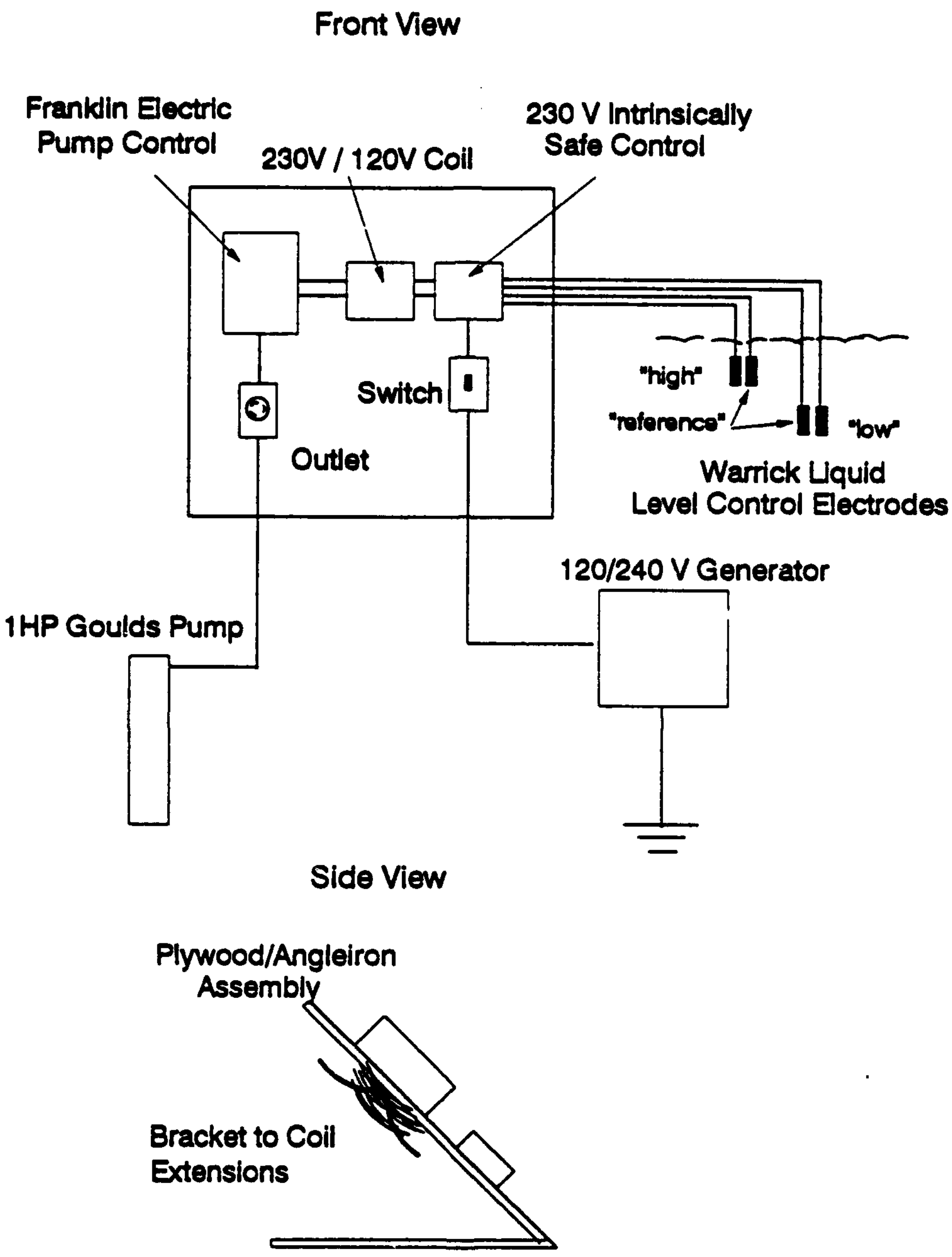


Figure 4-1. Portable Elect... Panel

measurements were compared with previous measurements for that particular gas vent and checked for inconsistencies.

Before and after each slug test the water wagon was weighed and the volume of leachate was calculated. The scale measured to the nearest 20 lbs or 0.32 ft^3 (assumed density of 62.4 lb/ft^3).

The pressure transducer was lowered into the gas vent first, and the cable was secured to the outside of the well casing with duct tape. Before the pump was lowered into the gas vent, the "low" liquid level control electrodes were firmly secured with electrical tape to the pump casing just above the pump intake.

Then, the first section of the 1-inch PVC discharge pipe was connected to the discharge of the pump. Two people slowly lowered the pump, held by two 70-foot lengths of aircraft cable, into the gas vent while a third person taped the pump electrical cables and the liquid level control electrode cables to the 1-inch discharge line in two to three foot intervals. All sharp edges and protrusions were taped with duct tape. Much care was taken to eliminate the possibility of getting the pump stuck in the gas vents.

The 1-inch PVC discharge pipe was marked in five foot intervals from the bottom of the pump. These markings provided a means of determining the optimum placement of the pump in the gas vents. The desired placement of the pump was within one foot from the bottom of the gas vent. The objective was to pump as much of the leachate as possible.

After the pump was lowered to the desired depth, the aircraft cables were secured to the generator hand bar and the truck bumper. The "high" electrodes were then lowered into the gas vent to just below the water table, and the cables were secured to the outside of the well casing with duct tape. The leachate level in the gas vent was monitored with the datalogger and the laptop computer. When the leachate level stabilized, the generator was started, the pump was plugged into the portable electrical panel with the switch on the panel located in the "off" position.

The hand-held push button switch on the datalogger was pushed and held for several seconds to clear the memory of the datalogger. Then, several measurements of the static leachate level were recorded in one second intervals and the real time of the initial reading was recorded. The pump was then turned on by the switch on the electrical panel, and pumping begun. Before the pump was switched on, it was necessary to increase the idle on the generator to provide enough current to start the pump. Measurements at one second intervals were made for the first four minutes of the test. For the remainder of the test the datalogger recorded leachate levels at 13.65 second intervals.

When the leachate in the gas vent was lowered to below the "low" electrodes, the pump shut off and the switch on the panel was quickly switched to the "off" position as a precautionary measure to ensure that the pump would not begin pumping while the leachate level was recovering. The water

wagon was weighed and the weight of water wagon plus the pumped leachate was recorded.

When the leachate in the gas vent recovered to 80% of the static level, a second slug test in that same gas vent was conducted. Two successive slug tests were conducted in gas vents #8, #20, and #33.

Leachate quality measurements. Before and after the pump slug test, leachate was sampled from the gas vents of the 11-acre and 33-acre units with a Teflon™ bailer. Conventional leachate parameters such as pH, conductivity, Total Dissolved Solids (TDS), chemical oxygen Demand (COD), Total Organic Carbon Content (TOC), and ammonia as nitrogen (NH_3-N) were analyzed. The purpose of the sampling was to determine the relative strength of the leachate before and after pumping and to demonstrate that the liquid pumped was leachate. The analytical methods utilized are outlined in Table 4-2.

Table 4-1. Leachate Constituent Analytical Methods

Parameter	Method	Equipment
pH	SM 423	Orion Combination pH Probe 91-06 Orion SA 230 portable pH meter
Conductivity	SM 205	Fisher Digital Conductivity Meter
TDS	SM 25406	Evaporate 180 C
COD	SM 52206	Hach Digestion Method Titrametric (FAS) Determination
TOC	SM 5310B	Ionic 555 Carbon Analyzer
NH3-N	SM 4500F	Orion 9512 Ammonia Gas Sensing Electrode
Cl-	SM 4110B	Dionex 2000i Ion Chromatograph

(American Public Health Association, et al. 1985)

CHAPTER 5
RESULTS AND DISCUSSION

Summary of Slug Test Results

The results of the PVC slug tests and the pump slug tests, illustrated in Figure 5-1, were categorized into three groups: the PVC slug test results, the early response pump slug test results, and the late response pump slug test results (see Figure 5-2). The results of the PVC slug tests (gas vents #8, #20, #21, #22, and #26) yielded K_s values that ranged from 8.6×10^{-4} to 1.5×10^{-2} cm/sec with a geometric mean of 2.5×10^{-3} cm/sec and a standard deviation of 4.0×10^{-4}. The early response of the pump slug tests (gas vents #8 and #20) yielded K_s values that ranged from 2.1×10^{-4} to 6.6×10^{-3} cm/sec with a geometric mean of 1.2×10^{-3} cm/sec and a standard deviation of 3.0×10^{-3}. The late response of the pump slug tests (gas vents #8, #20 and #33) yielded K_s values that ranged from 6.7×10^{-5} to 9.8×10^{-4} cm/sec with a geometric mean of 3.2×10^{-4} cm/sec and a standard deviation of 3.4×10^{-4}. The location of the gas vents tested is illustrated in Figure 5-3.

The geometric mean was selected as the best representation of the mean based on the work of several authors (Parsons (1945), Warren and Price (1961), and Bennion and Griffith (1966) as cited in Domenico and Schwartz, 1990).

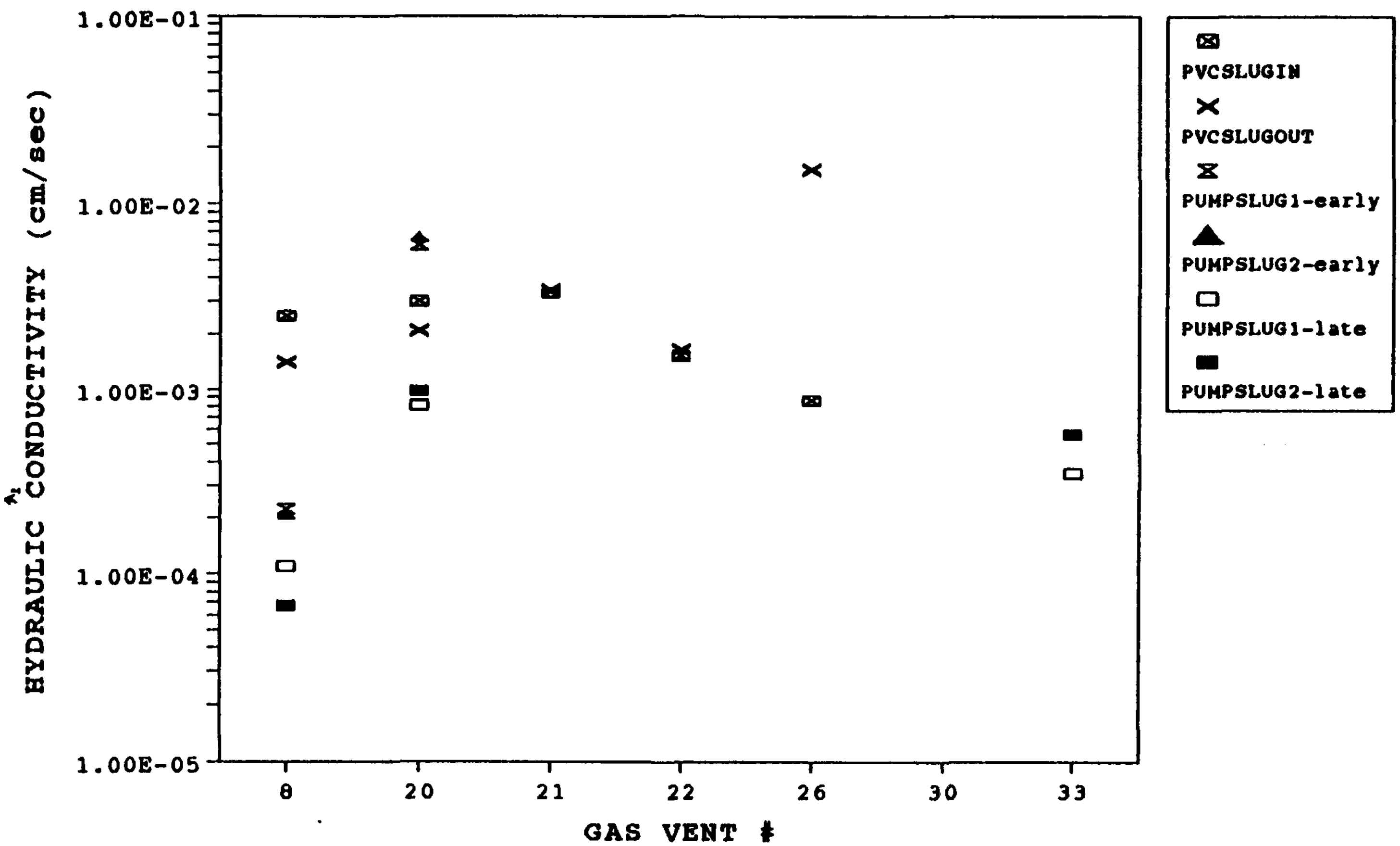


Figure 5-1. Summary of ACSWL Slug Test Results

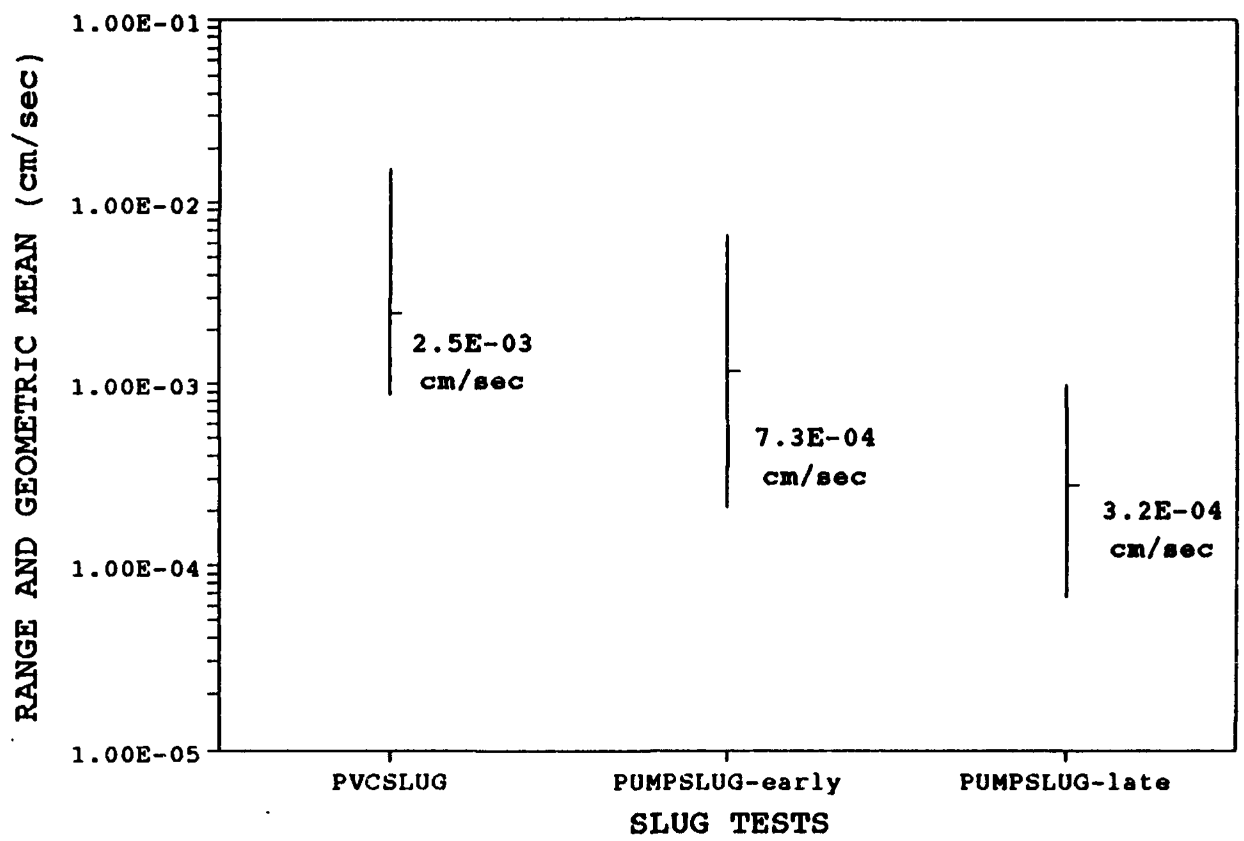


Figure 5-2. Slug Test Ranges and Geometric Means

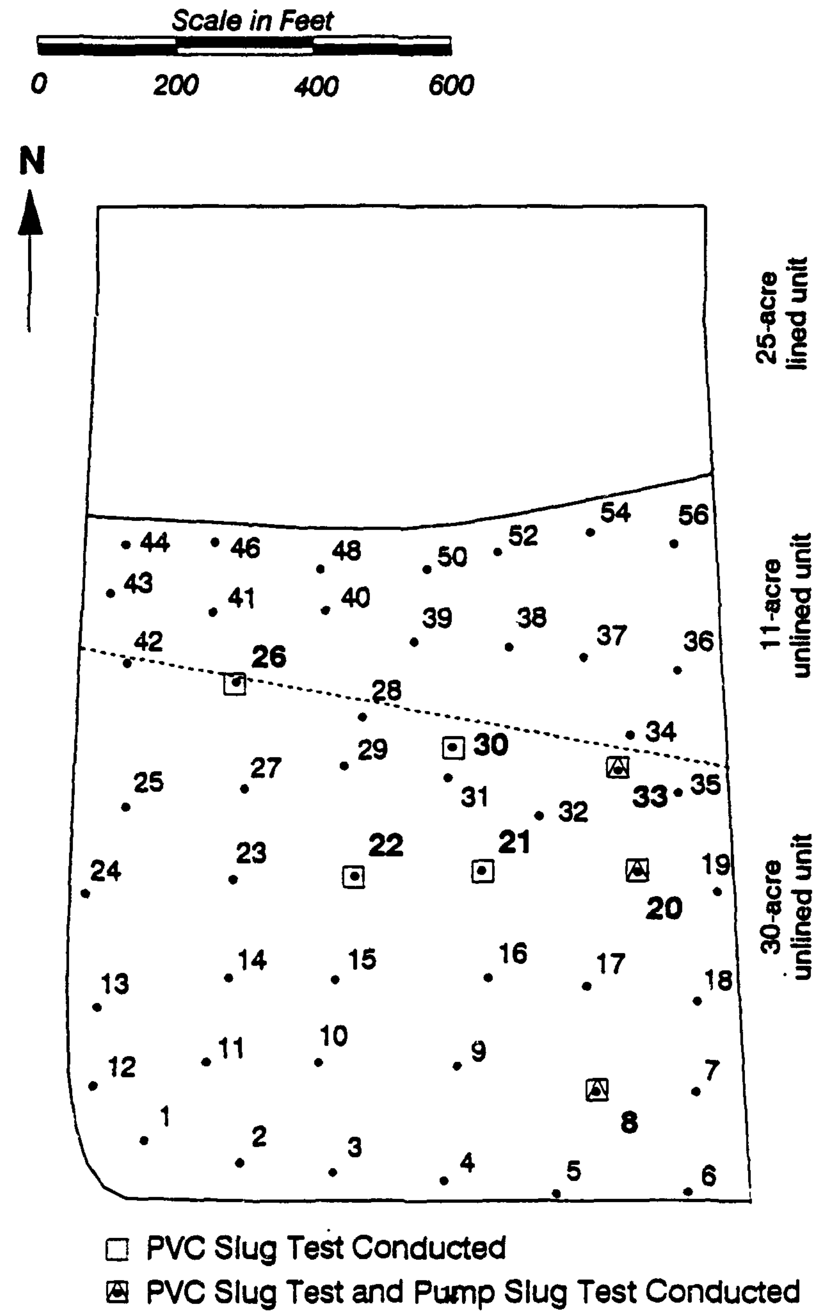


Figure 5-3. Gas Vent Layout with Tested Gas Vents Emphasized

The raw data and calculations for the PVC and the pump slug tests are provided in Appendices B and C, respectively.

PVC Slug Test Results

As stated previously, the results of the PVC slug tests in gas vents #8, #20, #21, #22, and #26 yielded K_s values that ranged from 8.6 x 10^{-4} to 1.5 x 10^{-2} cm/sec and had a geometric mean of ten measurements of 2.5 x 10^{-3} cm/sec (see Table 5-1). The K_s values represented the hydraulic conductivity of the gas vent gravel pack.

The effective radial distance, R_e, of the Bouwer and Rice (1976) model represents the theoretical radius from the gas vent where K was measured. Values of R_e were as large as 9.4 feet for gas vent #8. However, the raw data indicated that the PVC slug did not hydraulically affect the MSW beyond the 2-foot diameter gravel pack. The initial excess head, the change in head created by the injection of the 8-foot and 3-inch diameter PVC slug (0.393 ft^3) in the 6-inch section of the gas vent, was only 2.00 ft. The equivalent initial excess head in the 2-foot diameter gravel pack with an assumed porosity of 0.30 was only 0.364 ft. Bouwer (1978) recommended an initial excess head of 10 - 50 cm (0.33 - 1.64 ft) in the well for rate-of-rise applications; however, an initial excess head of 0.364 ft was insufficient to hydraulically affect the MSW. The record drawings indicated that the gravel pack was constructed of pea gravel. The grain size was not specified. Pea gravel has a grain size of 4 -19 mm and a porosity of 20 to 35% (Fetter,1988). Material of this size has a hydraulic

Table 5-1. Summary of PVC Slug Test Results

Gas Vent #	Test	Maximum Change in Head in Gas Vent (ft)	Maximum Change in Volume in Gas Vent (ft^3)	Effective Change in Head in Gravel Pack (ft)	Effective Radial Distance Re (ft)	Hydraulic Conductivity (cm/sec)
8	PVCSLUGIN	1.02	0.20	0.19		2.5E-03
	PVCSLUGOUT	0.54	0.11	0.10	9.4	1.4E-03
20	PVCSLUGIN	2.34	0.46	0.43		3.0E-03
	PVCSLUGOUT	0.66	0.13	0.12	5.6	2.1E-03
21	PVCSLUGIN	1.17	0.23	0.21		3.3E-03
	PVCSLUGOUT	0.54	0.11	0.10	5.1	3.4E-03
22	PVCSLUGIN	2.17	0.43	0.39		1.5E-03
	PVCSLUGOUT	0.62	0.12	0.11	5.1	1.6E-03
26	PVCSLUGIN	2.48	0.49	0.45		8.6E-04
	PVCSLUGOUT	0.59	0.12	0.11	7.4	1.5E-02
30	PVCSLUGIN	1.07	0.21	0.19		(a)
	PVCSLUGOUT	2.05	0.40	0.37	5.1	(a)
33	PVCSLUGIN	0.10	0.02	0.02		(a)
	PVCSLUGOUT	2.20	0.43	0.40	8.9	(a)

(a) no linear trend in semilog plot

HYDRAULIC CONDUCTIVITY (cm/sec)	
RANGE	8.6E-04 to 1.5E-02
GEOMETRIC MEAN	2.5E-03
ARITHMETIC MEAN	3.5E-03

conductivity that ranges from 10^{-1} to 10 cm/sec (Freeze and Cherry, 1979). The geometric mean of the PVC slug tests, 2.5 x 10^{-3} cm/sec, is more representative of a mixture of gravel and coarse sand with a K of 10^{-4} to 10^{-2} cm/sec. The lower values of hydraulic conductivity for the gravel pack are attributed to an undeveloped gravel pack and the PVC slug test methodology.

After construction, wells are fully developed by on-and-off pumping which causes the water to surge back and forth through the gravel pack and well screen to flush out fines. The flushing increases the well yield by removing fine particles from the gravel pack. The gas vents at ACSWL were installed for the purpose of gas collection and not leachate pumping and the gravel packs were never developed. This may have contributed to the lower values of hydraulic conductivity.

There was no physical evidence that the lower values of hydraulic conductivity for the gravel pack were the result of biofouling. The video survey indicated that there was some biofilm on the sidewalls of the gas vents in the 11-acre unit; however, there was no evidence of biofilm on the sidewalls of the 30-acre gas vents where the PVC slug tests were conducted.

The raw data indicates that the PVC slug was not injected or withdrawn instantaneously. In gravels and sands, instantaneous injection is even more difficult because the change in head is quickly dissipated as the slug is injected or withdrawn. At injection (or withdrawal) rates that

approximate instantaneous injection, a significant portion of the early response data are lost as a result of turbulence and a unique initial excess head and steady response is difficult to identify as was the case for gas vents #30, and #33. The semilog plots for these gas vents did not yield a significant linear trend, therefore the hydraulic conductivity for these gas vents was not determined.

Theoretically, it is impossible to inject a slug instantaneously without turbulence (Pandit and Miner, 1986). As stated previously, the initial excess head from the PVC slug is 2.00 ft in the absence of turbulence. Although several of the slug "in" tests achieved this value (see Table 5-1), much of the early response data was eliminated as a result of oscillations in the data points. Had more sensitive equipment been used to measure small changes in head, erroneous data points would have been easier to identify and eliminated. The Envirolab datalogger and transducers recorded and measured to the nearest one hundredth of a foot (+/-0.01 ft). With a small initial excess head in the gas vent of 2.00 ft equipment with a greater sensitivity should have been used. Without the early response data, a unique initial excess head was difficult to determine. To avoid erroneous data points from the fluctuations, the data points selected for the graphical solution generally did not include the first three 1-second interval data points as recommended by Pandit and Miner (1986).

The initial excess head for the slug "in" tests was closer to the theoretical value than the initial excess head of the slug "out" tests. This finding is contrary to field practices and may be attributed to the weight and size of the PVC slug. The sand-filled PVC slug (25 lbs) was awkward and difficult to maneuver. The large size was selected to maximize the displacement in the gas vent and the gravel pack in an effort to hydraulically affect the MSW. Two people were required to remove the slug (hand-over-hand) as quickly as possible for the slug "out" tests. For small changes in volume, as in the case of the PVC slug tests, a more rapid removal is necessary to minimize fluctuations and optimize instantaneous removal. Some of the fluctuations in the slug "out" tests may also be attributed to the troublesome size constraints of the 4-inch to 6-inch transition in the gas vents and movement of the transducer cable as the 3-inch diameter PVC slug was quickly removed from the gas vent. On several occasions, the PVC slug was lodged in what was believed to be the transition area of the gas vent as it was removed from the gas vent for the slug "out" tests.

Pump Slug Test Results

As stated previously, the results of the pump slug tests in gas vents #8, #20, and #33 were separated into two groups: early time response and late time response. The early time response K_s values ranged from 2.1×10^{-4} to 6.6×10^{-3} cm/sec with a geometric mean of 1.2×10^{-3} cm/sec, and the late time response K_s values ranged from 6.7×10^{-5} to 9.8 x

10^{-4} cm/sec with a geometric mean of 3.2×10^{-4} cm/sec (see Table 5-2). Two tests were conducted in gas vents #8, #20, and #33.

<u>Double straight line effect</u>. The Bouwer and Rice (1976) graphical solutions (see Appendix C) for gas vents #8 and #20 were indicative of the double straight line effect illustrated in Figure 5-4 and described by Bouwer (1989), whereas the graphical solution for gas vent #33 was not. In the initial publication of the Bouwer and Rice (1976) method, the authors assumed that the gravel pack or developed zone (in the absence of a gravel pack) drained at the same rate as the water level inside the well. However, some gravel packs or developed zones are not permeable enough to allow instantaneous drainage as in the case of gas vents #8 and #20, and semilog plots of the water level in the gas vent (y_t) over time (t) will yield a double straight line indicating the presence of two different materials of different hydraulic conductivities. Bouwer (1989) suggested that the double straight line anomaly was caused by drainage of the gravel pack or developed zone around the well after the water level is suddenly lowered. Immediately following the sudden lowering of the static water level in the well, the water in the gravel pack or developed zone quickly drains into the well until the water level in the gravel pack equals the water level inside the well (early time response) (AB of Figure 5-4). When drainage of the gravel pack or developed zone ceases, the rate of flow into the well decreases and a second straight line (late time response) is

Table 5-2. Summary of Pump Slug Test Results

Gas Vent #	Test	Static Head (ft)	Volume Pumped (ft^3)	Time to Pump (min)	Early and Late Times from Semilog Plot (min)		Initial Rate of Recharge (gpm)	Hydraulic Conductivity (cm/sec)
8	PUMPSLUG1	17.56	18.3	6.8	early	0.0 to 2.0	4.4	2.2E-04
					late	2.0 to 9.5	3.1	1.1E-04
	PUMPSLUG2	14.39	15.4	5.8	early	0.0 to 2.0	4.4	2.1E-04
					late	2.0 to 13.0	2.1	6.7E-05
20	PUMPSLUG1	15.11	12.2	4.6	early	0.0 to 0.4	9.6	6.0E-03
					late	0.8 to 2.9	5.6	8.2E-04
	PUMPSLUG2	12.40	12.8	4.8	early	0.0 to 0.3	13.7	6.6E-03
					late	0.5 to 2.2	6.7	9.8E-04
33	PUMPSLUG1	20.45	24.7	9.2	late	0.0 to 10.0	6.1	3.5E-04
	PUMPSLUG2	15.56	17.7	6.6	late	0.0 to 6.0	9.9	5.7E-04

EARLY TIME HYDRAULIC CONDUCTIVITY (cm/sec)			
RANGE	2.1E-04	to	6.6E-03
GEOMETRIC MEAN			1.2E-03
ARITHMETIC MEAN			3.3E-03

LATE TIME HYDRAULIC CONDUCTIVITY (cm/sec)			
RANGE	6.7E-05	to	9.8E-04
GEOMETRIC MEAN			3.2E-04
ARITHMETIC MEAN			4.8E-04

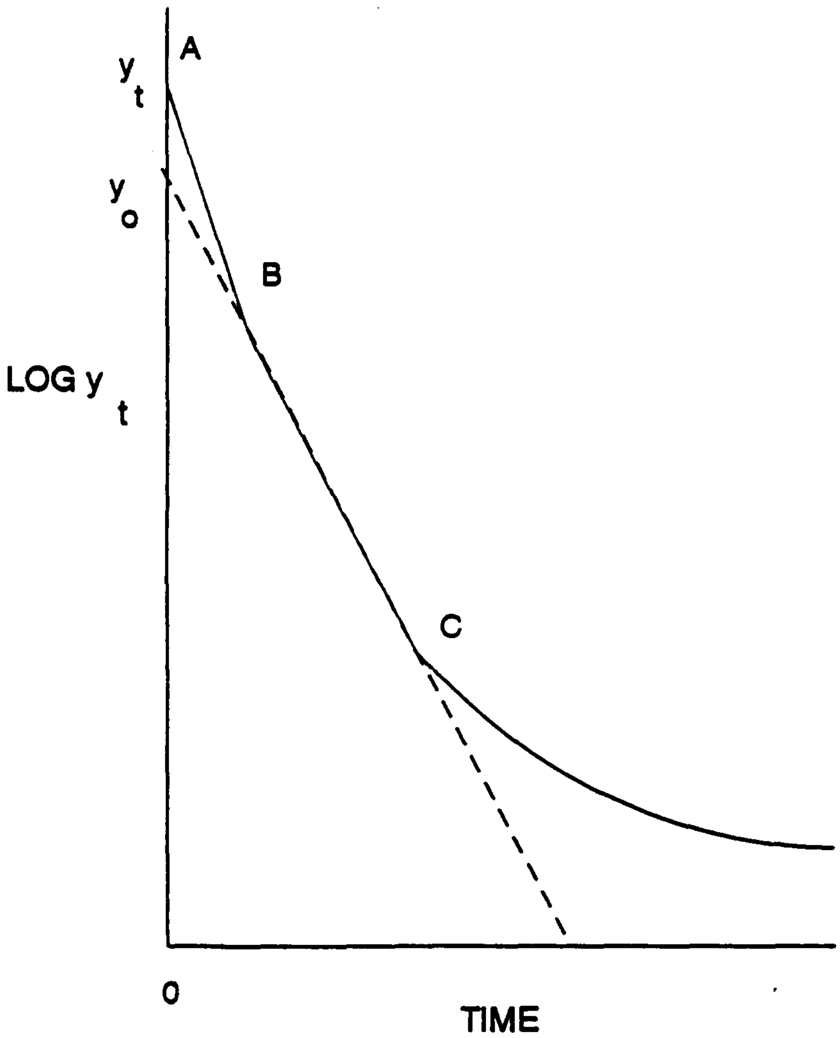


Figure 5-4. Double Straight Line Effect
(adapted from Bouwer, 1989)

formed (BC of figure 5-4). Bouwer (1989) suggested that the second straight line (late time) is more representative of the flow from the undisturbed aquifer into the well. Bouwer (1989) also suggested that the data deviate from a straight line (C of Figure 5-4) at small values of drawdown (y) as a result of measurement errors. Data in this region of the semilog plot are disregarded.

Leachate quality. The leachate quality was measured as part of the pump slug tests to determine the nature and the source of the leachate pumped. On the basis of the parameters measured (TOC, BOD, COD, pH, conductivity, and ammonia), the liquid pumped was confirmed as leachate (see Table 5-3) and the leachate was removed from the MSW matrix as a result of pumping. A comparison of leachate constituent concentrations before and after gas vents #8, #20, and #33 were pumped indicated an increase in strength after they were pumped (see Table 5-4). The increase in the leachate constituent concentrations was attributed to physical contact with MSW as compared to the leachate which had drained into the gravel pack and was stored in the gas vents and gravel pack pores since the construction of the gas vents. Gas vent #8 had the greatest increase in constituent concentration followed by gas vents #20 and #33. Gas vent #8 was located in the oldest section of the landfill. The age of the MSW in the vicinity of gas vent #8 was approximately 13 years older than the MSW in the vicinity of gas vent #33. The early time response K_s values ranged from 2.1×10^{-4} for gas vent #8 (PUMPSLUG2) to

Table 5-3. Gas Vent Leachate Constituent Concentrations

11-acre and 30-acre Gas Vent Leachate (a)					
Gas Vent # (a)	pH	Conductivity (umhos/cm)	TDS (mgl)	COD (mgl)	NH3-N (mgl)
2	NM	930	NM	62	4
5	NM	NM	NM	55	7
7	3.21	1650	574	70	45
8	3.50	1650	958	187	47
12	NM	1040	NM	50	3
17	NM	1230	NM	67	26
20	3.28	2730	834	205	50
21	6.03	1070	646	48	4
22	6.34	1240	536	55	16
26	6.46	2880	1178	149	68
28	6.74	4710	1966	405	110
30	6.85	4380	1836	344	118
33	6.38	2470	618	92	36
41	7.54	13500	3970	2068	1236
52	7.23	9050	3512	1463	450
25-acre Lift Station Leachate (Raw) (b)					
Gas Vent #	pH	Conductivity (umhos/cm)	TDS (mgl)	COD (mgl)	NH3-N (mgl)
Minimum	6.5	1130	560	20	12
Maximum	7.9	7400	3619	2286	298

"NM" not measured

(a) Sampled 9/15/92 and 10/7/92

(b) Sampled from 1988 - 1992 (Miller and Townsend, 1992)

Table 5-4. Comparision of Leachate Constituent Concentrations from Gas Vents Before and after Pump Slug Tests

Gas Vent #	Date of Pump Slug Test	Sampling Date	Cl- (mg/l)	COD (mg/l)	TOC (mg/l)	NH3-N (mg/l)
8	10/24/92	9/15/92	156	187	91	47
		11/02/92	795	925	241	432
20	10/23/92	9/15/92	80	205	48	50
		11/02/92	172	259	72	111
33	10/22/92	9/15/92	71	92	29	36
		11/02/92	75	135	46	65

6.6 x 10^{-3} cm/sec for gas vent #20 (PUMPSLUG2) and had a geometric mean of 1.2 x 10^{-3} cm/sec. The early time response of the pump slug tests represented the dewatering of the gravel pack by gravity drainage after the gas vents were dewatered to a level just above the pump intake. The gas vents were not completely dewatered to prevent the pump from pumping "dry" and generating excess heat from friction in the presence of combustible gases typical of most landfills.

Comparison with PVC slug test results. The early time response of the pump slug tests was comparable to the results of the PVC slug tests previously discussed although the area of the gravel pack measured was different. The PVC slug test results represented the horizontal hydraulic response to an initial excess head of two feet and at an elevation near the phreatic leachate level in the gas vent. The results of the early time pump slug tests represent the hydraulic response to an initial excess head of twelve to fifteen feet at an elevation near the bottom of the gas vent. The hydraulic response of the gravel pack to the pump slug test represented the residual gravity drainage of the gravel pack.

The absence of a double straight line for gas vent #33 indicated that the gravel pack was very permeable and was dewatered during pumping. This conclusion was confirmed by the rapid response of the gravel pack to the PVC slug for gas vent #33. The response was so rapid that the datalogger and transducer were not able to record the response.

Late Time Response Results

The late time response K_s values ranged from 6.7×10^{-5} to 9.8×10^{-4} cm/sec with a geometric mean of six measurements of 3.2×10^{-4} cm/sec. These values are representative of the MSW in the vicinity of the gas vents tested. The double straight line of the semilog plots and the increase in the leachate quality between the pump slug tests confirmed that the hydraulic conductivity of MSW in the vicinity of the gas vent was measured.

ACSWL K Comparison With Values Cited in the Literature

The geometric mean of 3.2×10^{-4} cm/sec for the K_s of the MSW at the ACSWL compares favorably with laboratory results of Miller et al. (1989) and the field test results of Oweis et al. (1990) (see Figure 5-5). The hydraulic conductivity of MSW determined by Oweis et al. (1990) and Miller et al. (1989) represented the saturated K of MSW as compared to the unsaturated hydraulic conductivity reported by EMCON Associates (1983) and the vertical K_s reported by Townsend (1992).

The geometric mean of 3.2×10^{-4} cm/sec for the K_s of the MSW at the ACSWL is less than the hydraulic conductivity of 1×10^{-3} cm/sec determined from a pumping test conducted at a landfill in New Jersey (Oweis et al. 1990). The pump slug test results measured the static response of the ACSWL MSW to a sudden change in head whereas the results of the pumping test conducted by Oweis et al. (1990) measured the steady state response of a landfill to a change in head. The results

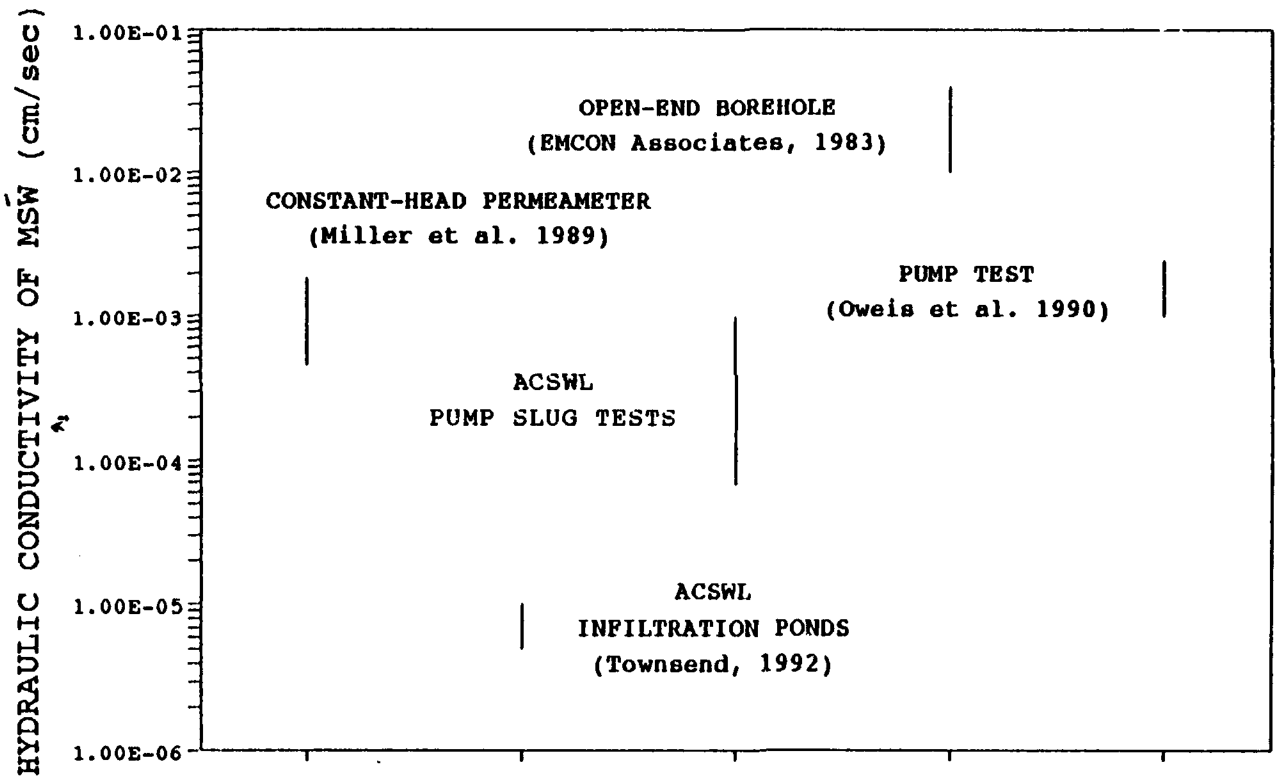


Figure 5-5. ACSWL Hydraulic Conductivity & Values Cited in the Literature

of the pump slug test also measured the hydraulic conductivity in the vicinity of the gas vents tested whereas the results of the pumping test measured the hydraulic conductivity over a greater distance from the pumping well.

The geometric mean for the pump slug tests was greater than the range of hydraulic conductivity of 5×10^{-6} to 1×10^{-5} cm/sec determined from a water balance of infiltration ponds at the ACSWL in the 25-acre lined unit (Townsend, 1992). The hydraulic conductivity determined from slug tests and pumping tests (Oweis et al. 1990) represents the horizontal component of the hydraulic conductivity (Domenico and Schwartz, 1990) whereas the hydraulic conductivity determined from the infiltration ponds (Townsend, 1992) represents the vertical component of the hydraulic conductivity. The hydraulic conductivity determined from slug tests has a component in the vertical direction but most of the head loss is predominantly dissipated in the horizontal direction (Bouwer, 1978).

The difference in magnitude between the vertical and horizontal hydraulic conductivity was attributed to the anisotropic nature of the MSW in a landfill. Landfill practices of tightly compacting large layers of MSW in cells and covering with smaller layers of more permeable daily cover material create horizontal stratifications within the landfill matrix.

Application of the Bouwer and Rice (1976) Method

The electrical analogs for both fully and partially penetrating wells yield values of ln R_e/r_w that are within 10% of the actual value if the screened length of the well (L_e) is greater than 40% of the length of the well below the water table (L_w) and within 25% if the screened length of the well (L_e) is much less (for example, 10%) than the length of the well below the water table (L_w). All of the gas vents tested at ACSWL had a screen length (L_e) greater than 40% of the length of the well below the water table (L_w).

Gas Vent Geometry and Assumptions

In addition to the assumptions associated with most radial flow applications (i.e. homogeneity, isotropy, and negligible well losses), several assumptions regarding the gas vent geometry were also necessary. Gas vent parameters derived from field measurements and/or derived on the basis of several assumptions included the depth of the leachate (L_w), the saturated thickness of the landfill (H), the length of the perforated section of the gas vent (L_e), the diameter of the gravel pack ($2r_w$), and the porosity of the gravel pack (n).

Saturated thickness. The depth of the leachate (L_w), the measured depth of the bottom (or obstruction) of the gas vent, the surveyed elevations of the gas vents (CH2M-Hill, 1992b), and an assumed bottom elevation of the landfill of 70 m.s.l. (Bruner, 1992), were utilized to determine the saturated thickness (H) of the landfill. If the calculated bottom elevation of the gas vent (or obstruction) was less than the

assumed bottom elevation of the landfill (70 m.s.l.), the bottom elevation of the landfill was assumed to be equivalent to the elevation of the bottom (or obstruction) of the gas vent. As a result of this assumption, gas vent #8 was the only tested gas vent assumed to be fully penetrating for the slug test analysis. The assumed bottom elevation of the landfill at gas vent #8 was 65.08 ft m.s.l.. The impact of this assumption was measured by a hypothetical increase in the saturated thickness of the landfill at gas vent #8 of one foot so the assumption that the gas vent is partially penetrating could be made. This increase in the saturated thickness would decrease the calculated K_s by 20%. This phenomena may be attributed to the vertical flow gradients created in the vicinity of a partially penetrating pumped well.

An isometric plot of the leachate levels in the gas vents was constructed (see Figure 5-6). Cross-sectional profiles of the landfill were also constructed (see Figures 5-7 and 5-8 (a) through (f)). The raw data for the isometric plot and the profiles are provided in Appendix A. For the purpose of constructing the profiles, the assumptions were also made that: (1) the MSW below the static leachate levels in the gas vents was fully saturated (i.e. the leachate was not "perched" within the landfill), and (2) that leachate levels less than less than six inches were considered extraneous as a result of false readings from condensate on the sidewalls of the gas vents.

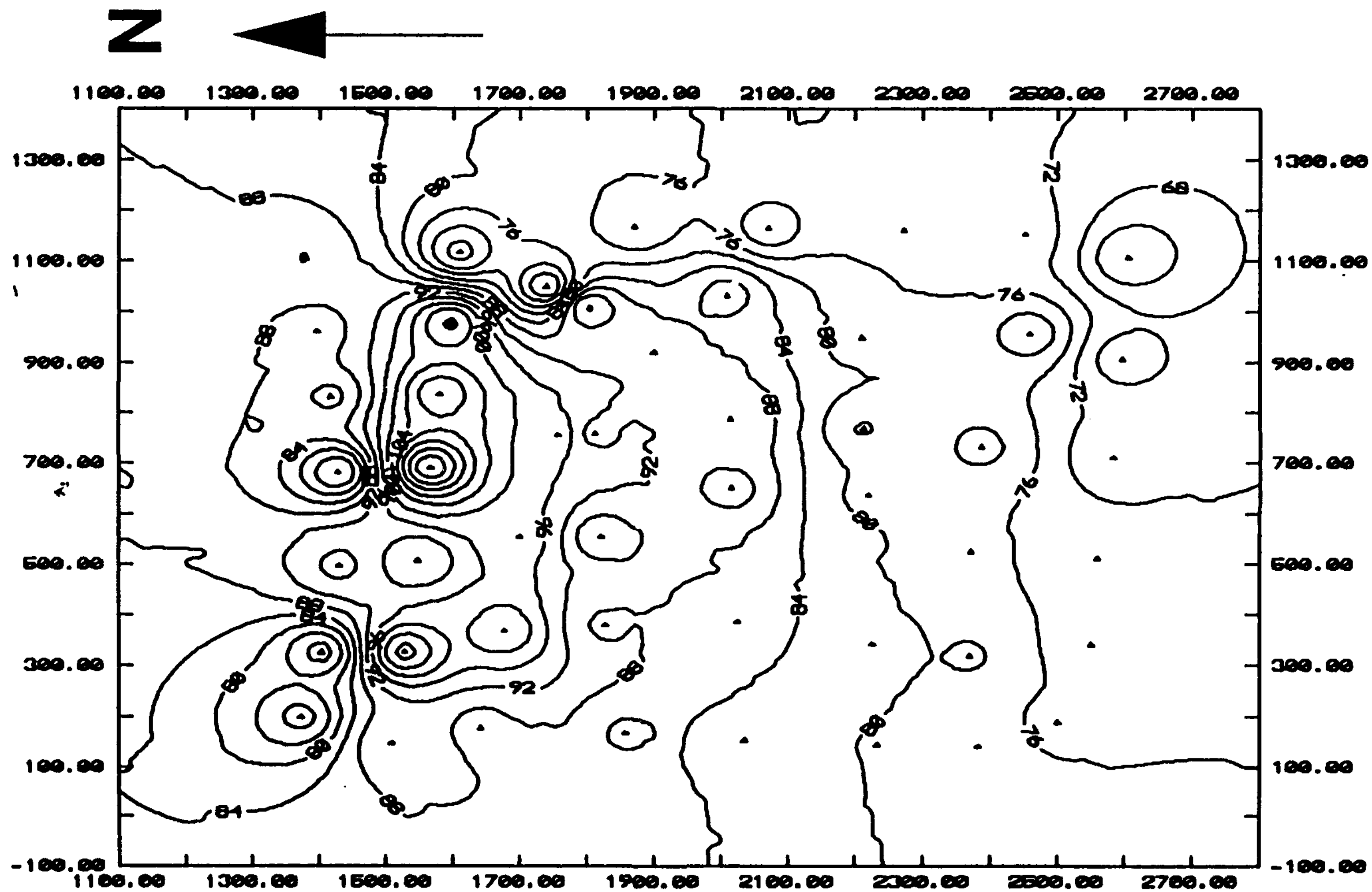


Figure 5-6. Isometric Plot of Leachate Elevations (m.s.l.) in 30-acre and 11-acre Gas Vents

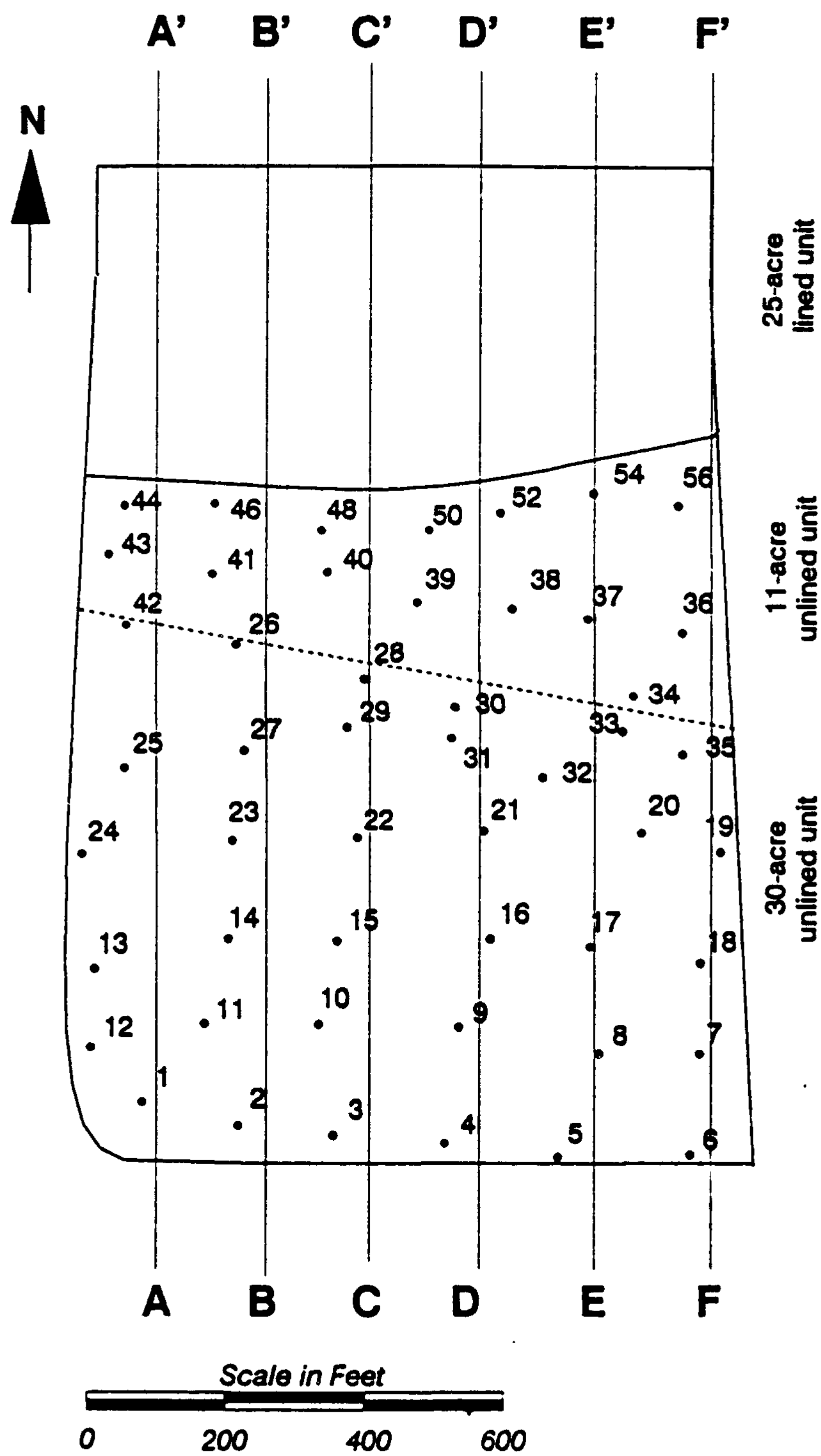


Figure 5-7. Gas Vent Layout with Cross-sections Shown

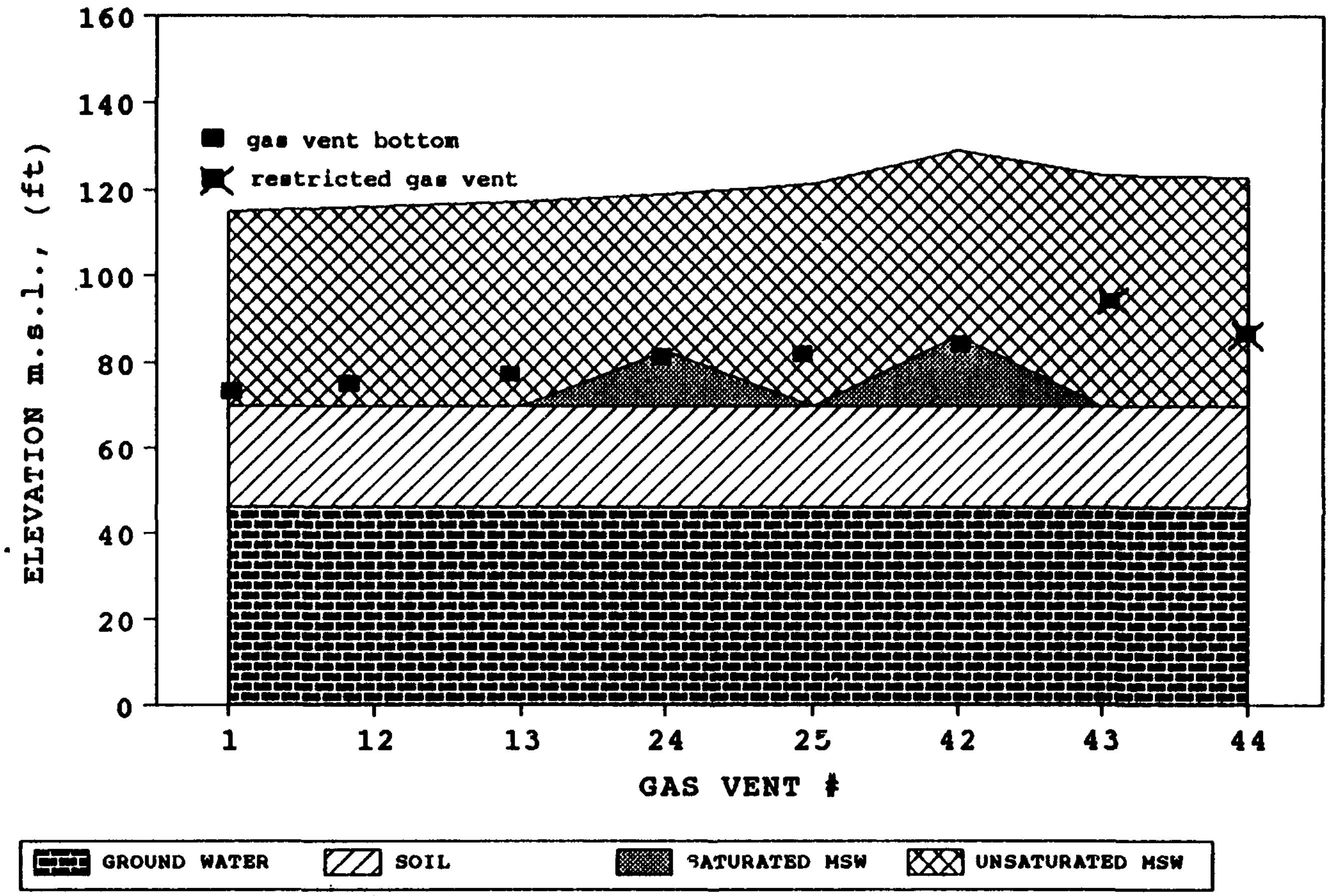


Figure 5-8. 30-acre and 11-acre Unit Cross-sections:
(a) A-A'

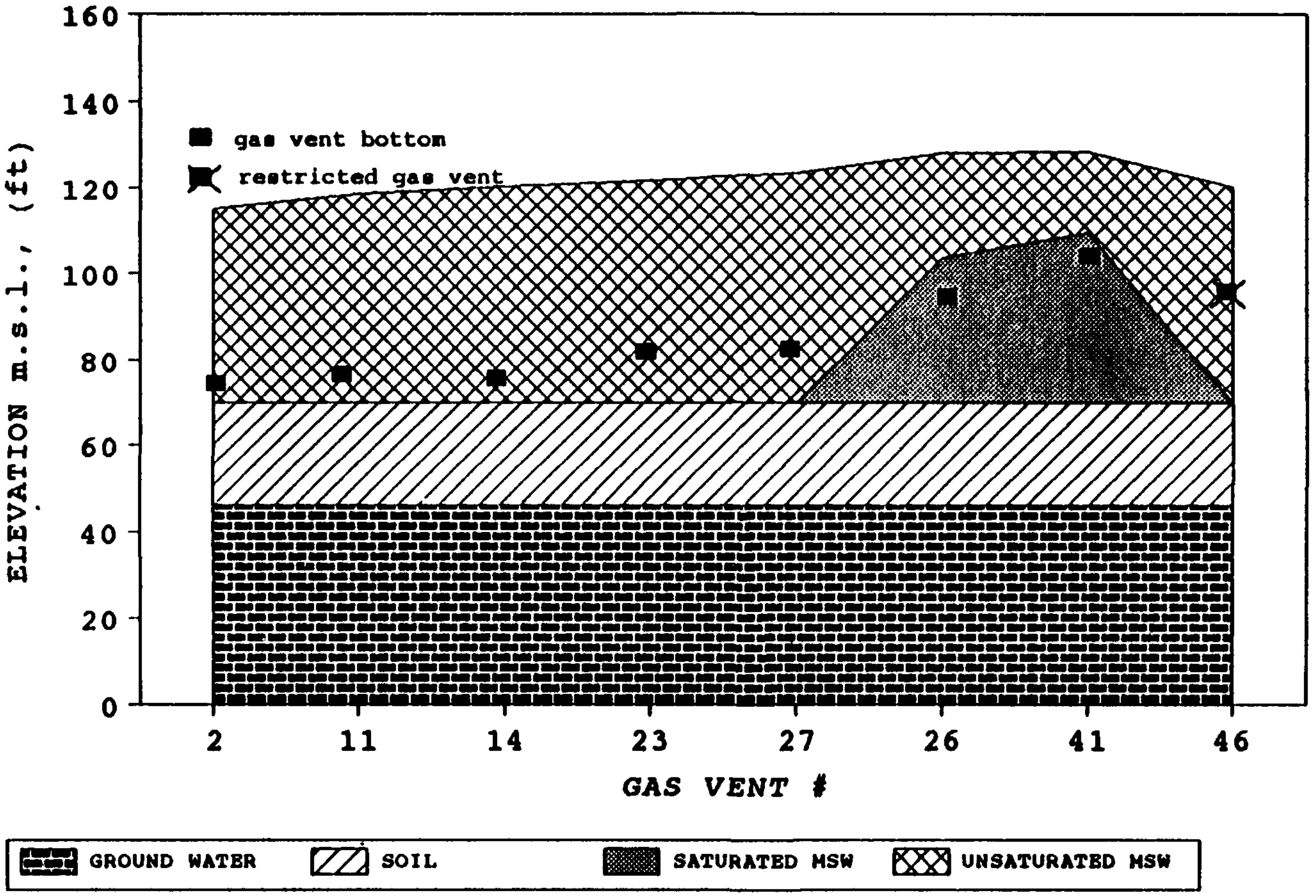


Figure 5-8. 30-acre and 11-acre Unit Cross-sections: (b) B-B'

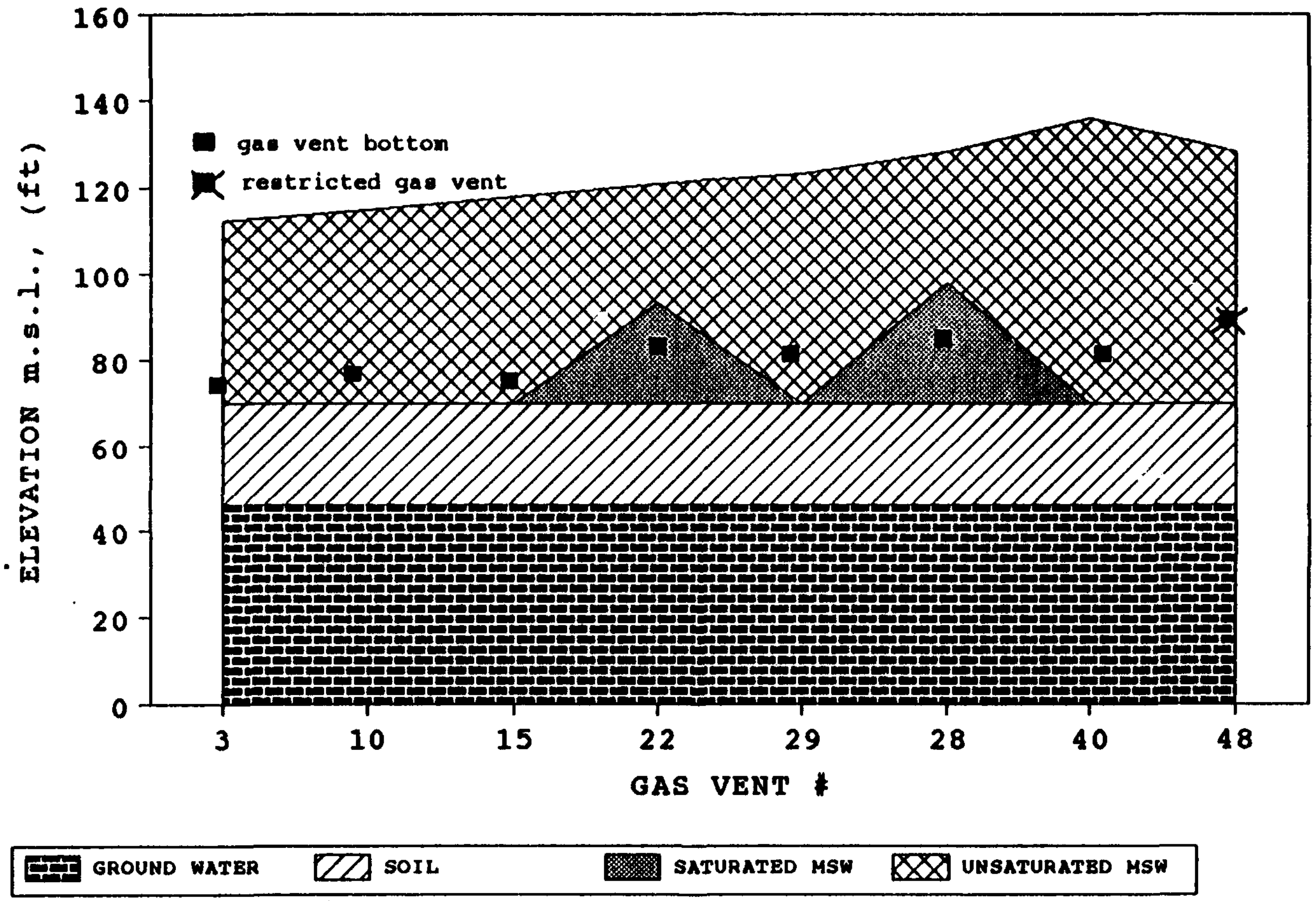


Figure 5-8. 30-acre and 11-acre Unit Cross-sections:
(c) C-C'

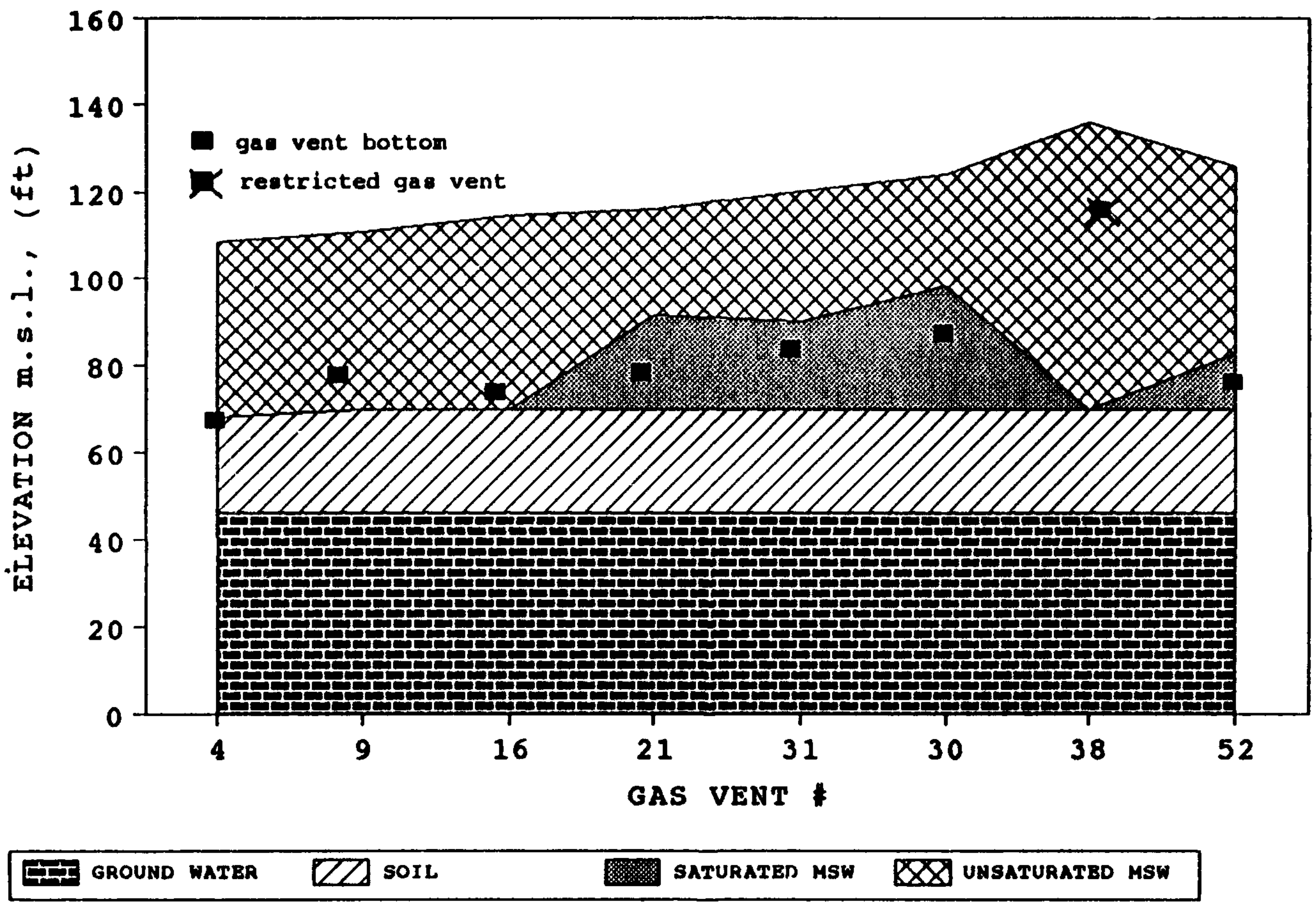


Figure 5-8. 30-acre and 11-acre Unit Cross-sections: (d) D-D'

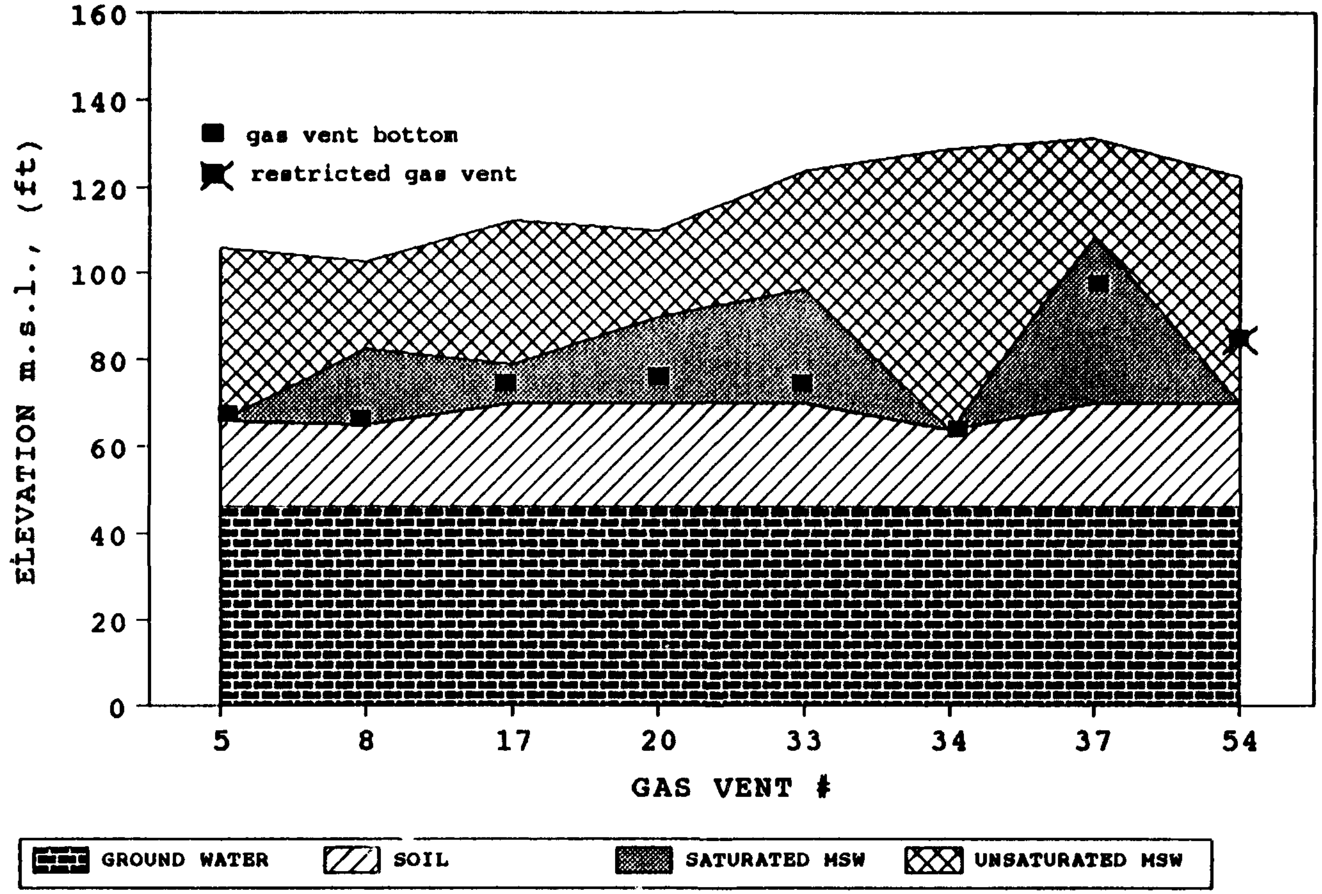


Figure 5-8. 30-acre and 11-acre Unit Cross-sections:
(e) E-E'

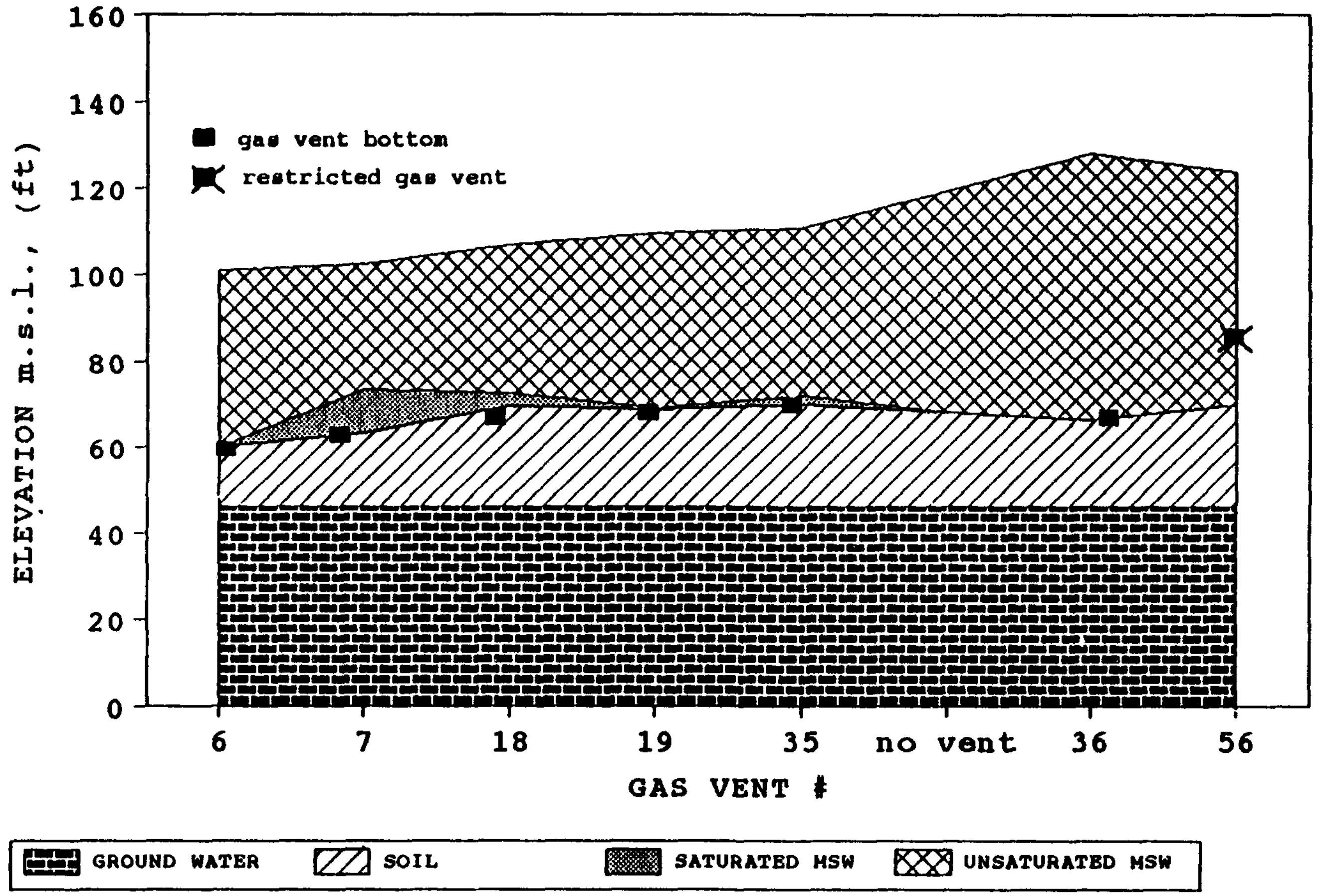


Figure 5-8. 30-acre and 11-acre Unit Cross-sections:
(f) F-F'

Length of the perforated section. The lengths of the perforated sections, L_e, were not assumed to be consistent with the record drawings provided by CH2M-Hill (1992b) in all cases. As previously discussed, the record drawings indicated that the 30-acre unit gas vents, at a minimum, had a 20-foot section of 6-inch slotted PVC and one of three variations for the bottom fifteen feet of the 4-inch PVC segment. Two of the variations described the gas vents in which the slug tests were conducted: the full length was perforated (gas vents #8, #22, #30 and #33), or the bottom had hand sawed perforations (gas vents #20, #21, and #26). However, the length of the perforated section for gas vents #20, #21, and #26 was assumed to be 20 feet because there was no indication of the length of the hand sawed section in the record drawings. The value of L_e is a significant parameter in that it represents the height of the landfill over which K_s was measured. For an increase in the perforated length from 20 feet (gas vents #20, #21, and #26) to 35 feet (gas vents #8, #22, #30 and #33) for any of the gas vents tested, the calculated K_s increased by 10%.

Diameter of the gravel pack. Bouwer (1989) suggested that inaccuracies in the estimates of the gravel pack thickness have a greater effect on the calculated hydraulic conductivities for small well casings than for larger well casings. A range for small well casings was not provided. The diameter of the gravel pack was assumed to be in accordance with the record drawings (CH2M-Hill, 1992b). However, the record drawings indicated that the 2-foot

diameter was the minimum diameter required of the drilling contractor. A two-fold increase in the assumed borehole diameter of the gas vents tested would have yielded nearly a two-fold increase in the calculated hydraulic conductivity.

Porosity of the gravel pack. As previously discussed, the gravel pack was constructed of pea gravel ranging from 20 to 35% (Fetter, 1988). A porosity of 30.0% was assumed. Prior to the slug PVC tests the gravel pack had not been developed to remove any fines accumulated during the construction of the gas vents and the extent of biofouling in the gravel pack could not be determined.

Instantaneous Slug Removal by Pumping

An additional assumption unique to the slug test theory was the instantaneous removal of a slug by pumping. The application of this method warrants further discussion. The use of a submersible pump to instantaneously dewater a "slug" of leachate was a unique variation of the traditional slug test methodology. Pandit and Miner (1986) suggested the assumption of instantaneous removal was reasonable if the early time of the semilog plot is 10% of the time required to dissipate (or recharge) 80% of the initial excess head (the volume of the slug injected or removed). This assumption was valid for all of the semilog plots of gas vents #8, #20, and #33.

A comparison of the pumping rate and the initial recharge rate suggested that the magnitude of the gravel pack hydraulic conductivity had some bearing on the instantaneous removal of

the pumped slug. The initial discharge rate of the 1HP submersible pump was 20 gpm. In comparison, the initial recharge rate of the gas vents ranged from 4.4 gpm (gas vent #8) to 13.7 gpm (gas vent #20) (see Table 5-2) and the corresponding hydraulic conductivities were 1.1 x 10^{-4} cm/sec (gas vent #8) and 6.6 x 10^{-3} cm/sec (gas vent #20). For gas vent #8, the ratio of the pumping rate to the recharge rate, 20 gpm (discharge) to 4.4 gpm (recharge), was greater and therefore more instantaneous than gas vent #20 (20 gpm to 13.3 gpm). For aquifer materials with an estimated hydraulic conductivity of the order 10^{-4} cm/sec, the removal of a slug by pumping can be considered more instantaneous than for aquifer materials with a hydraulic conductivity of the order 10^{-3} cm/sec.

Hydraulic Conductivity of the MSW at ACSWL

Gas vents #8, #20, #33 span the landfill from north to south, the same direction in which filling proceeded. The cross-sectional drawing (see Figure 5-8 (e)) indicates an increase in the saturated thickness (18 to 26 feet) of the landfill with a decrease in the age of the MSW. The difference in the age of the MSW in the vicinity of gas vents #8 and #33 is approximately 13 years.

The isometric plot of the gas vent leachate levels (see Figure 5-6) indicated that the radial extent of the saturated MSW in the vicinity of gas vent #20 was greater than the radial extent of the saturated MSW in the vicinity of gas vents #8 and #33. The increased volume of saturated MSW

surrounding gas vent #20 is believed to be the cause of the increased hydraulic conductivity of the MSW measured near this gas vent.

CHAPTER 6
SUMMARY AND CONCLUSIONS

The existing layout of the gas vents of the ACSWL, a series of slug tests were selected as a means of determining the *in situ* hydraulic conductivity of the MSW. The average distance between the gas vents, 150 feet, and the approximate range of MSW hydraulic conductivity in the literature (10^{-3} to 10^{-5} cm/sec) eliminated the possibility of conducting a pump test. The slug test provided a simple and economical means for determining several "point" hydraulic conductivities throughout the ACSWL.

The geometric mean of six measurements gave a value of 3.2×10^{-4} cm/sec as the saturated horizontal conductivity, $K_{s,h}$ of the MSW in the vicinity of the gas vents tested. The results ranged from 6.7×10^{-5} to 9.8×10^{-4} cm/sec. The range of values is attributed to the heterogeneities and the anisotropic nature of landfilled MSW. The MSW sample size ranged from 5 to 9 ft in radius from the gas vents tested. These gas vents (#8, #20, and #33) were aligned to form a cross-section of the landfill spanning a distance of approximately 700 ft and an age of 14 years (20 to 6 years).

The traditional methodology for conducting slug tests was successfully modified. A submersible pump was used to instantaneously remove a "slug" of leachate from 6-inch PVC

landfill gas vents. The submersible pump simulated the instantaneous removal necessary to hydraulically impact the MSW. The ability of a pump to instantaneously remove a slug will depend on the estimated hydraulic conductivity of the material being tested. For material with a hydraulic conductivity of the order 10^{-4} cm/sec, the removal of a slug by pumping will be more instantaneous than for materials with a hydraulic conductivity of the order 10^{-3} cm/sec.

Slug tests conducted with a very large volumetric slug made of PVC piping were unsuccessful at measuring the hydraulic conductivity of the MSW and were more representative of the 2-foot diameter gravel pack surrounding the gas vents. The large diameter gravel pack hydraulically insulated the MSW from any small changes in head.

The hydraulic conductivity measured by the pumped slug test method represents the static response of the MSW to a sudden change in head. The sample size of the MSW represented in this study as defined by the Bouwer and Rice (1976) method of analysis was approximately five to nine feet from the center of the gas vent and approximately twenty feet in height.

The results of the traditional slug test method using a slug constructed of PVC piping confirmed the early time response results of the pump slug method.

The results of the early time response of the pumped slug tests for gas vents #8 and #20 were indicative of the double straight line effect (Bouwer, 1989). Bouwer (1989) attributed

the double straight line in the semilog plot of the excess head versus time to the delayed gravel pack drainage in response to the slug. The absence of a double straight line for gas vent #33 indicated that the gravel pack was very permeable and was dewatered during pumping. This conclusion was confirmed by the rapid response of the gravel pack to the PVC slug for gas vent #33.

The presence of the double straight line of the semilog plots and the increase in the leachate quality between the pump slug tests confirmed that the hydraulic conductivity of MSW in the vicinity of the gas vent was measured.

Variations in the results of the PVC slug tests and the pump slug test results were the result of the size of the slug removed by the two different methods. The results of the PVC slug represented the horizontal hydraulic response to an initial excess head of two feet and at an elevation near the phreatic leachate level in the gas vent whereas the results of the early time pump slug tests represent the hydraulic response to an initial excess head of twelve to fifteen feet at an elevation near the bottom of the gas vent.

The difference in magnitude between the vertical hydraulic conductivity for landfilled MSW cited in the literature (Townsend, 1992) and the horizontal hydraulic conductivity determined from this study is attributed to the anisotropic nature of the MSW in a landfill.

Profiles of the saturated thickness and the results of the slug tests suggested that the hydraulic conductivity of

the MSW was higher in areas of the landfill where the radial extent of the saturated MSW was the greatest and lower in areas of the landfill where the radial extent of the saturated MSW was less.

Pumped slug tests with the instantaneous removal of leachate by means of a pump is an inexpensive and viable means of determining several point hydraulic conductivities of landfilled MSW. An accurate assessment of the hydraulic conductivity for a landfill can be determined for points at pump rates high enough to hydraulically affect the MSW.

APPENDIX A
ACSWL GAS VENT MEASUREMENTS

Table A-1. History of 11-acre Unit Gas Vent Leachate Levels

GAS VENT #	DEPTH OF LEACHATE							
	10/3/91 (FT)	11/8/91 (FT)	1/8/92 (FT)	2/5/92 (FT)	2/21/92 (FT)	3/14/92 (FT)	5/4/92 (FT)	9/19/92 (FT)
34	4.30	0.40	0.05	0.00	0.00	---	---	---
36	5.40	1.63	0.75	1.53	0.00	---	---	---
37	0.40	0.00	0.00	0.00	0.00	---	---	---
38	0.40	4.30	0.00	0.00	2.20	---	---	1.60
39	0.40	0.00	0.05	0.00	1.90	---	---	---
40	0.00	7.80	6.50	0.00	6.30	6.20	0.00	---
43	8.90	4.05	2.70	3.00	2.20	---	---	15.60
44	12.50	11.55	14.00	10.30	9.70	10.10	6.80	0.20
44	12.50	7.55	6.30	6.50	5.40	6.20	6.60	2.20
46	15.60	0.00	13.00	0.00	0.00	0.00	0.00	0.20
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.80
50	0.40	0.50	0.10	0.10	0.00	---	---	0.30
52	8.40	8.90	0.10	4.55	4.20	---	---	0.30
54	0.00	0.00	0.00	0.00	0.00	---	---	0.20
56	4.40	0.40	0.10	0.00	0.00	---	---	---

" ---" no measurements taken

Table A-2. 30-acre and 11-acre Unit Gas Vent Field Measurements

GAS VENT #	ELEVATION	FIELD MEASUREMENTS RAW/CALCULATIONS 9/19/92								
	(a) m.s.l	NATURAL GRADE TO TOP OF CONCRETE (b) in.	TOP OF CONCRETE TO TOP OF PVC (b) in.	DEPTH TO LEACHATE FROM TOP OF PVC (PROBE) (b) ft.	DEPTH TO BOTTOM FROM TOP OF PVC (PROBE) (b) ft.	DEPTH OF LEACHATE (PROBE) ft.	DEPTH OF LEACHATE (TAPE) (b) ft.	DEPTH TO BOTTOM FROM TOP OF PVC (TAPE) (b) ft.	AVERAGE DEPTH TO BOTTOM ft.	AVERAGE DEPTH OF LEACHATE ft.
1	115.0	6.0	22.0	no access - cleanout not installed by contractor this date						
2	115.2	19.0	24.8	45.1	45.6	0.5	0.3	45.5	45.5	0.4
3	112.4	8.5	24.0	42.5	42.8	0.3	0.2	42.7	42.7	0.2
4	108.7	10.5	21.8	43.0	43.1	0.2	0.3	43.1	43.1	0.2
5	105.8	10.0	24.0	42.6	42.9	0.3	0.2	42.9	42.9	0.2
6	101.0	18.0	22.8	44.1	44.4	0.3	0.2	44.4	44.4	0.2
7	102.4	12.0	23.0	32.1	42.3	10.2	10.4	42.0	42.1	10.3
8	103.2	0.0	24.0	22.7	40.1	17.4	17.8	40.2	40.1	17.6
9	111.0	18.0	22.0	33.9	34.1	0.3	0.2	33.1	33.6	0.2
10	115.1	18.0	23.8	42.3	42.3	0.0	0.2	42.4	42.3	0.1
11	118.5	9.0	23.0	40.9	40.9	0.0	0.2	40.9	40.9	0.1
12	116.2	16.0	22.8	41.1	41.3	0.2	0.2	41.4	41.3	0.2
13	117.4	18.0	25.8	40.7	40.8	0.1	0.2	41.8	41.3	0.2
14	120.4	8.0	23.0	41.3	41.3	0.0	0.0	41.4	41.3	0.0
15	118.1	17.0	23.3	42.2	42.4	0.2	0.2	42.4	42.4	0.2

(a) FORESIGHT SURVEYORS, INC. 4/18/92
(b) RAW DATA
(c) EQUIPMENT STUCK IN OBSTRUCTED GAS VENT, NO FURTHER MEASUREMENTS THIS DATE
(d) LATERAL GAS VENT, 90 DEGREE ELBOW BELOW COVER SYSTEM
(e) NO GAS VENT

Table A-2.--continued

GAS VENT #	ELEVATION	FIELD MEASUREMENTS RAW/CALCULATIONS 9/19/92								
		NATURAL GRADE TO TOP OF CONCRETE	TOP OF CONCRETE TO TOP OF PVC	DEPTH TO LEACHATE FROM TOP OF PVC (PROBE)	DEPTH TO BOTTOM FROM TOP OF PVC (PROBE)	DEPTH OF LEACHATE (PROBE)	DEPTH OF LEACHATE (TAPE)	DEPTH TO BOTTOM FROM TOP OF PVC (TAPE)	AVERAGE DEPTH TO BOTTOM	AVERAGE DEPTH OF LEACHATE
	(a) m.s.l	(b) in.	(b) in.	(b) ft.	(b) ft.	ft.	(b) ft.	(b) ft.	ft.	ft.
16	114.8	13.0	24.5	42.3	42.6	0.5	0.4	42.7	42.6	0.5
17	112.6	11.0	24.0	38.2	38.5	3.4	3.3	41.2	39.8	3.3
18	107.0	12.0	21.5	38.6	38.9	3.2	3.3	41.6	40.2	3.2
19	109.9	13.0	23.0	43.8	44.0	0.6	0.6	44.0	44.0	0.6
20	110.4	10.0	23.3	23.6	37.5	14.0	14.5	37.6	37.5	14.2
21	116.3	15.0	23.0	28.1	40.7	12.5	12.9	40.6	40.6	12.7
22	121.0	11.0	19.5	30.6	39.9	9.3	9.7	39.7	39.8	9.5
23	121.9	10.0	23.0	38.3	38.5	0.2	0.3	38.5	38.5	0.2
24	119.4	13.0	23.5	39.9	40.[illegible]	0.4	0.7	40.3	40.2	0.5
25	121.7	14.5	26.5	41.9	42.1	0.3	0.5	42.1	42.1	0.4
26	128.5	5.0	26.5	32.8	46.2	13.4	14.2	36.2	41.2	13.8
27	123.7	17.0	24.0	39.8	39.8	0.0	0.0	39.8	39.8	0.0
28	128.4	14.5	24.8	33.8	41.9	8.2	8.5	41.9	41.9	8.3
29	123.3	13.5	23.5	41.8	42.1	0.3	0.5	42.0	42.0	0.4
30	124.2	16.0	23.5	29.5	45.5	16.1	16.6	45.5	45.5	16.3

(a) FORESIGHT SURVEYORS, INC. 4/18/92
(b) RAW DATA
(c) EQUIPMENT STUCK IN OBSTRUCTED GAS VENT, NO FURTHER MEASUREMENTS THIS DATE
(d) LATERAL GAS VENT, 90 DEGREE ELBOW BELOW COVER SYSTEM
(e) NO GAS VENT

Table A-2.--continued

GAS VENT #	ELEVATION	FIELD MEASUREMENTS RAW/CALCULATIONS 9/19/92								
	(NOTE 1) m.s.l	NATURAL GRADE TO TOP OF CONCRETE (NOTE 2) in.	TOP OF CONCRETE TO TOP OF PVC (NOTE 2) in.	DEPTH TO LEACHATE FROM TOP OF PVC (PROBE) (NOTE 2) ft.	DEPTH TO BOTTOM FROM TOP OF PVC (PROBE) (NOTE 2) ft.	DEPTH OF LEACHATE (PROBE) ft.	DEPTH OF LEACHATE (TAPE) (NOTE 2) ft.	DEPTH TO BOTTOM FROM TOP OF PVC (TAPE) (NOTE 2) ft.	AVERAGE DEPTH TO BOTTOM ft.	AVERAGE DEPTH OF LEACHATE ft.
31	120.5	15.5	24.0	33.9	39.9	6.0	6.6	39.9	39.9	6.3
32	113.0	10.0	24.0	25.7	37.9	12.2	12.7	37.7	37.8	12.4
33	124.1	12.0	23.3	30.9	51.2	20.3	20.7	51.2	51.2	20.5
34	128.8	14.5	25.3	68.4	68.4	0.0	0.2	68.4	68.4	0.1
35	110.9	15.0	25.5	42.1	42.1	0.0	0.2	42.1	42.1	0.1
36	128.3	9.5	24.5	64.7	64.8	0.1	0.2	64.8	64.8	0.1
37	131.6	13.0	22.0	55.0	58.7	3.8	3.5	0.0	29.4	3.6
38	136.1	11.0	20.8	27.0	27.0	0.0	0.0	27.1	27.0	0.0
39	138.1	4.5	24.0	15.0	31.2	16.2	14.7	33.9	32.5	15.5
40	136.0	13.0	21.0	43.2	46.0	2.8	0.0	58.7	52.3	1.4
41	128.6	6.0	22.0	21.6	27.3	5.7	5.9	27.3	27.3	5.8
42	129.6	14.0	24.5	46.7	46.9	0.2	0.8	46.9	46.9	0.5
43	123.8	6.0	24.3	22.8	22.8	0.0	0.0	46.9	34.9	0.0
44	123.0	(c)								
45	(d)									

(a) FORESIGHT SURVEYORS, INC. 4/18/92
(b) RAW DATA
(c) EQUIPMENT STUCK IN OBSTRUCTED GAS VENT, NO FURTHER MEASUREMENTS THIS DATE
(d) LATERAL GAS VENT, 90 DEGREE ELBOW BELOW COVER SYSTEM
(e) NO GAS VENT

Table A-2.--continued

GAS VENT #	ELEVATION	FIELD MEASUREMENTS RAW/CALCULATIONS 9/19/92								
		NATURAL GRADE TO TOP OF CONCRETE	TOP OF CONCRETE TO TOP OF PVC	DEPTH TO LEACHATE FROM TOP OF PVC (PROBE)	DEPTH TO BOTTOM FROM TOP OF PVC (PROBE)	DEPTH OF LEACHATE (PROBE)	DEPTH OF LEACHATE (TAPE)	DEPTH TO BOTTOM FROM TOP OF PVC (TAPE)	AVERAGE DEPTH TO BOTTOM	AVERAGE DEPTH OF LEACHATE
	(NOTE 1)	(NOTE 2)	(NOTE 2)	(NOTE 2)	(NOTE 2)		(NOTE 2)	(NOTE 2)		
	m.s.l	in.	in.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
46	120.5	(c)								
47	(d)									
48	128.5	(c)								
49	(d)									
50	132.0	(c)								
51	(d)									
52	126.2	12.0	23.0	49.9	53.9	4.0	4.2	46.9	50.4	4.1
53	(d)									
54	122.6	4.0	29.3	39.3	39.3	0.0	0.0	39.3	39.3	0.0
55	(e)									
56	124.0	11.0	23.3	34.8	34.8	0.0	0.0	34.8	34.8	0.0

(a) FORESIGHT SURVEYORS, INC. 4/18/92
(b) RAW DATA
(c) EQUIPMENT STUCK IN OBSTRUCTED GAS VENT, NO FURTHER MEASUREMENTS THIS DATE
(d) LATERAL GAS VENT, 90 DEGREE ELBOW BELOW COVER SYSTEM
(e) NO GAS VENT

Table A-3. Gas Vent Video Transcripts (7/92)

FLORIDA JETCLEAN INC. TRANSCRIPTS

TAPE 1 TRACK #		GAS VENT #	TOP OF PVC TO TOP OF LEACHATE (FT)	TOP OF PVC TO BOTTOM OF VENT (FT)	CONDITION
0000	0345	24	40	43	GOOD CONDITION
0350	0640	13	42	44	GOOD CONDITION
0650	0960	1	45	46	GOOD CONDITION
0965	1290	2	40	44	GOOD CONDITION
1295	1595	3	48	49	GOOD CONDITION
1595	1870	4	44	46	GOOD CONDITION
1875	2098	5	NONE	47	GOOD CONDITION
2100	2290	6	40	42	GOOD CONDITION
2300	2590	7	38	46	GOOD CONDITION
2615	2780	18	42	45	GOOD CONDITION
2790	3000	19	47	49	GOOD CONDITION
3010	3200	35	NONE	45	GOOD CONDITION
3300	3462	44		32	LINE RESTRICTED
3662	3750	45			90 DEGREE ELBOW
3770	3950	46			90 DEGREE ELBOW
3955	4150	47		25	LINE RESTRICTED
4150	4257	48		38	LINE RESTRICTED
4260	4320	49			90 DEGREE ELBOW
4340	4400	50		34	LINE RESTRICTED
4415	4495	51			90 DEGREE ELBOW
4550	4650	52		51	LINE RESTRICTED
4660	4850	53		30	RUPTURED AND SPLIT
4860	4900	54			90 DEGREE ELBOW
4920	5050	56		38	LINE RESTRICTED BY ROOTS
5065	5227	36	56	58	GOOD CONDITION
5228	5534	37		32	HEAVY SCALE - RESTRICTIONS
5540	5640	38		29	HEAVY SCALE - RESTRICTIONS
5650	5700	39		36	HEAVY SCALE - RESTRICTIONS
5710	5815	40		48	HEAVY SCALE - OBSTRUCTED
5820	5932	41		49	HEAVY SCALE - OBSTRUCTED
5940	6050	43		24	
6057	6115	42	48	50	GOOD CONDITION
6120	6220	26	34	48	GOOD CONDITION
6225	6310	28		45	HEAVY SCALE - OBSTRUCTED
6311	6360	30		48	HEAVY SCALE - OBSTRUCTED
6362	6415	33	50	54	GOOD CONDITION
6420	6500	34	70	72	GOOD CONDITION

Table A-3.--continued

FLORIDA JETCLEAN INC. NARRATION, TAPE 1

GAS VENT #	TOP OF PVC TO TOP OF LEACHATE (FT)	TOP OF PVC TO BOTTOM OF WELL (FT)	CONDITION "()" denote visual display
	44	(~45)	GOOD CONDITION
13	(~32)	33	GOOD CONDITION
1	NONE	43	GOOD CONDITION
2	46	46.5	GOOD CONDITION
3	(~45)	46	GOOD CONDITION
4	46	46.5	GOOD CONDITION
5	44	45.5	GOOD CONDITION
6	47	48	GOOD CONDITION
7	38	46	GOOD CONDITION
18	42	45	GOOD CONDITION
19	47	(~48)	GOOD CONDITION
35	NONE	45	GOOD CONDITION
44	(NONE)	32	RESTRICTED
45	(N/A)	(N/A)	90 DEGREE ELBOW
43	(NONE)	24	RESTRICTED
	(N/A)	(N/A)	90 DEGREE ELBOW
48	(NONE)	34	COLLAPSED & RUPTURED
	(N/A)	(N/A)	90 DEGREE ELBOW
50	(NONE)	34	RESTRICTED
51	(N/A)	(N/A)	90 DEGREE ELBOW
52	51	56	GOOD CONDITION, (BULGE/51')
53	(NONE)	52	RESTRICTED (RUPTURED/30'& 51')
54	(N/A)	(N/A)	90 DEGREE ELBOW
56	(NONE)	38	RESTRICTED (HOSE)
36	66	(~67)	GOOD CONDITION
37	(NONE)	32	(NOT VISIBLE -BIOFILM)
38	(NONE)	29	(NOT VISIBLE -BIOFILM)
39	(NONE)	36	(NOT VISIBLE -BIOFILM)
40	(NONE)	48	RESTRICTED
41	13	30	(NOT VISIBLE)
43	(NONE)	24	COLLAPSED
42	48	50	GOOD CONDITION
26	34	48	(NOT VISIBLE)
28	35	45	(NOT VISIBLE)
30	30	48	GOOD CONDITION
33	32	54	GOOD CONDITION
34	70	72	GOOD CONDITION

Table A-3.--continued

FIELD VERIFICATION, TAPE 1

GAS VENT #	TOP OF PVC TO TOP OF LEACHATE (FT)	TOP OF PVC TO BOTTOM OF WELL (FT)	CONDITION
24	44	~45	GOOD CONDITION
13	43.7	43.3	GOOD CONDITION, NOTE 1
1	NONE	43	GOOD CONDITION
2	46	46.5	GOOD CONDITION
3	~45	46	GOOD CONDITION
4	46	46.5	GOOD CONDITION
5	44	45.5	GOOD CONDITION
6	47	48	GOOD CONDITION
7	38	46	GOOD CONDITION
18	42	45	GOOD CONDITION
19	47	~48	GOOD CONDITION
35	NONE	45	GOOD CONDITION
44	NONE	32	RESTRICTED
45	N/A	N/A	90 DEGREE ELBOW
46	NONE	24	RESTRICTED
47	N/A	N/A	90 DEGREE ELBOW
48	NONE	34	COLLAPSED & RUPTURED
49	N/A	N/A	90 DEGREE ELBOW
50	NONE	34	RESTRICTED
51	N/A	N/A	90 DEGREE ELBOW
52	51	56	GOOD CONDITION
53	NONE	52	RESTRICTED & RUPTURED
54	N/A	N/A	90 DEGREE ELBOW
56	NONE	38	RESTRICTED BY HOSE
36	66	~67	GOOD CONDITION
37	NONE	32	RESTRICTED OR COLLAPSED
38	NONE	29	RESTRICTED OR COLLAPSED
39	NONE	36	RESTRICTED OR COLLAPSED
40	NONE	48	RESTRICTED
41	13	30	CONDITION QUESTIONABLE
43	NONE	24	COLLAPSED
42	48	50	GOOD CONDITION
26	34	48	GOOD CONDITION
28	35	45	GOOD CONDITION
30	30	48	GOOD CONDITION
33	32	54	GOOD CONDITION
34	70	72	GOOD CONDITION

Table A-3.--continued

A TRANSCRIPT WAS NOT PROVIDED FOR TAPE 2

NARRATION AND VISUAL DISPLAY, TAPE 2

TRACK #'S		GAS VENT #	TOP OF PVC TO TOP OF LEACHATE (FT)	TOP OF PVC TO BOTTOM OF VENT (FT)	CONDITION "()" denote visual display
0000	0045		40	42	GOOD CONDITION, (NOT VISIBLE)
0045	0096	9	(~37)	38	GOOD CONDITION, (NOT VISIBLE)
0096	0150	10	(~33)	34	GOOD CONDITION, (NOT VISIBLE)
0150	0192		(~33)	34	GOOD CONDITION, (NOT VISIBLE)
0192	0250	15	40	46	GOOD CONDITION, (NOT VISIBLE)
0250	0302	16	NONE	32	GOOD CONDITION, (NOT VISIBLE)
0302	0350	17	NONE	40+	GOOD CONDITION, (NOT VISIBLE)
0350	0437	23	(~32)	42	GOOD CONDITION, (NOT VISIBLE)
0437	0519	23	(~32)	43	GOOD CONDITION, (NOT VISIBLE)
0519	0590	32	28	30	GOOD CONDITION, (NOT VISIBLE)
0590	0707	31	38	45	GOOD CONDITION, (NOT VISIBLE)
0707	0798	29	44	45	GOOD CONDITION, (NOT VISIBLE)
0798	0957		NONE	10	RESTRICTED, (NOT VISIBLE)
0957	1109		NONE	16	RESTRICTED, GRAVEL?
1109	1235		3[illegible]		BUBBLING
1235	1346		NONE	40+	PARTIALLY COLLAPSED

Table A-3.--continued

FIELD VERIFICATION, TAPE 2

GAS VENT #	TOP OF PVC TO TOP OF LEACHATE (FT)	TOP OF PVC TO BOTTOM OF VENT (FT)	CONDITION
(a)	40	42	CONDITION IS QUESTIONABLE
9	~37	38	CONDITION IS QUESTIONABLE
(b)	~33	34	CONDITION IS QUESTIONABLE
(c)	~33	34	CONDITION IS QUESTIONABLE
(d)	40	46	CONDITION IS QUESTIONABLE
16	NONE	32	CONDITION IS QUESTIONABLE
17	NONE	40+	GOOD CONDITION
(e)	~32	42	CONDITION IS QUESTIONABLE
(e)	~32	43	CONDITION IS QUESTIONABLE
32	28	30	CONDITION IS QUESTIONABLE
(f)	38	45	CONDITION IS QUESTIONABLE
29	44	45	CONDITION IS QUESTIONABLE
(g)	NONE	10	RESTRICTED
(g)	NONE	16	RESTRICTED BY GRAVEL
(g)	38	38	CONDITION IS QUESTIONABLE
(g)	NONE	40+	COLLAPSED

(a) BASED CONTRACTOR'S PATH (PER RON SCHOL OF CH2M-HILL) SHOULD BE #8
CANNOT BE #8, FIELD MEASUREMENTS INDICATE 17' OF LEACHATE

(b) CANNOT BE #10 , BASED ON FIELD MEASUREMENTS OF VENT

(c) BASED PATH (PER RON SCHOL OF CH2MHILL) SHOULD BE #11 OR #14
CANNOT BE #11 OR #14, FIELD MEASUREMENTS INDICATE 6' OF LEACHATE

(d) CANNOT BE #15, FIELD MEASUREMENTS INDICATE .7' OF LEACHATE

(e) CANNOT BE #23, FIELD MEASUREMENTS INDICATE .2' OF LEACHATE

(f) CANNOT BE #31, FIELD MEASUREMENTS INDICATE 2.2' OF LEACHATE

(g) VENTS IN LINED CELL PER RON SCHOL OF CH2M-HILL

Table A-4. Field Verification of Video Survey

GAS VENT #	FIELD MEASUREMENTS: DEPTH TO OBSTRUCTION FROM TOP OF PVC 07/08/92 PROBE (FT)	DEPTH TO OBSTRUCTION FROM TOP OF PVC 07/08/92 2" PIPE (FT)	DEPTH TO LEACHATE FROM TOP OF PVC 07/08/92 PROBE (FT)	DEPTH OF LEACHATE BASED ON PROBE 07/08/92 (FT)	VIDEO TAPE: DEPTH TO OBSTRUCTION FROM TOP OF PVC 05/28/92 (FT)	DEPTH TO LEACHATE FROM TOP OF PVC 05/28/92 (FT)	DEPTH OF LEACHATE BASED ON VIDEO 05/28/92 (FT)
1 THRU 7	DATA PROVIDED ON VIDEO NOT QUESTIONABLE THEREFORE NO FIELD MEASUREMENTS						
8	42.2	41.2	25.3	16.9	NOT VERBALLY IDENTIFIED ON TAPE		
9	36.0	34.9	36.0	0.0	38	(~37)	1
10	44.0	---	43.7	0.3	34	(~33)	1
11	44.3	---	44.0	0.3	NOT VERBALLY IDENTIFIED ON TAPE		
12	45+	40.5	42.5	2.5	NOT VERBALLY IDENTIFIED ON TAPE		
13	43.7	---	43.3	0.4	42	44	6
14	43.3	---	43.3	0.0	NOT VERBALLY IDENTIFIED ON TAPE		
15	44.2	---	43.5	0.7	46	40	6
16	WASP'S NEST ON ELBOW, NO FIELD MEASUREMENTS				32	NONE	NONE
17	43.3	41.4	41.9	1.4	40	NONE	NONE
18	43.8	---	40.9	2.9	45	42	10
19	46.3	---	46.0	0.3	(~48)	47	10
20	39.5	38.2	23.5	16.0	NOT VERBALLY IDENTIFIED ON TAPE		

'---' no measurements, confirmed by history of data

Table A-4.--continued

GAS VENT #	FIELD MEASUREMENTS: DEPTH TO OBSTRUCTION FROM TOP OF PVC 07/08/92 PROBE (FT)	DEPTH TO OBSTRUCTION FROM TOP OF PVC 07/08/92 2" PIPE (FT)	DEPTH TO LEACHATE FROM TOP OF PVC 07/08/92 PROBE (FT)	DEPTH OF LEACHATE BASED ON PROBE 07/08/92 (FT)	VIDEO TAPE: DEPTH TO OBSTRUCTION FROM TOP OF PVC 05/28/92 (FT)	DEPTH TO LEACHATE FROM TOP OF PVC 05/28/92 (FT)	DEPTH OF LEACHATE BASED ON VIDEO 05/28/92 (FT)
21	42.8	41.0	30.3	12.5	NOT VERBALLY IDENTIFIED ON TAPE		
22	42.0	40.0	33.0	9.0	NOT VERBALLY IDENTIFIED ON TAPE		
23	40.6	---	40.4	0.2	42	(~32)	10
24	42.1	---	41.8	0.3	45	44	1
25	44.0	---	43.7	0.3	NOT VERBALLY IDENTIFIED ON TAPE		
26	47.2	---	33.3	13.9	48	34	14
27	42.2	---	42.2	0.0	NOT VERBALLY IDENTIFIED ON TAPE		
28	43.2	---	34.5	8.7	45	35	10
29	43.8	---	43.5	0.3	45	44	1
30	48.7	30.5	29.7	19.0	48	30	18
31	42.2	---	40.0	2.2	45	38	7
32	29.0	28.1	27.8	1.2	30	28	2
33	52.1	---	31.5	20.6	54	32	22
34 THRU 5	DATA PROVIDED ON VIDEO NOT QUESTIONABLE THEREFORE NO FIELD MEASUREMENTS						

'---' no measurements, confirmed by history of data

Table A-5. Gas Vent Measurements for Cross-sections

	RAW DATA - (9/92)				CALCULATIONS		ASSUME LANDFILL BOTTOM ELEVATION OELEV = 70.0 m.s.l; OELEV < or = LBELEV		
GAS VENT #	GAS VENT ELEVATION AT GRADE VELEV m.s.l (ft)	DEPTH OF GAS VENT ABOVE GRADE h (ft)	AVERAGE DEPTH TO OBSTRUCTION DTO (ft)	AVERAGE DEPTH OF LEACHATE DOL (ft)	GAS VENT OBSTRUCTION ELEVATION OELEV m.s.l (ft)	GAS VENT LEACHATE ELEVATION LELEV m.s.l (ft)	YES H = DOL H (ft)	NO H = DOL + x x (ft)	NO H = DOL + x H (ft)
1 (a)	115.0	2.3	43.0	0.0	74.4	74.4		4.4	4.4
2	115.2	3.6	45.5	0.4	73.3	73.7		3.3	3.7
3	112.4	2.7	42.7	0.2	72.4	72.6		2.4	2.6
4	108.7	2.7	43.1	0.2	68.3	68.5	0.2		
5	105.8	2.8	42.9	0.2	65.7	65.9	0.2		
6	101.0	3.4	44.4	0.2	60.0	60.2	0.2		
7	102.4	2.9	42.1	10.3	63.2	73.5	10.3		
8	103.2	2.0	40.1	17.6	65.1	82.7	17.6		
9	111.0	3.3	33.6	0.2	80.7	80.9		10.7	10.9
10	115.1	3.5	42.3	0.1	76.3	76.4		6.3	6.4
11	118.5	2.7	40.9	0.1	80.3	80.4		10.3	10.4
12	116.2	3.2	41.3	0.2	78.1	78.3		8.1	8.3
13	117.4	3.6	41.3	0.2	79.8	79.9		9.8	9.9
14	120.4	2.6	41.3	0.0	81.7	81.7		11.7	0.0
15	118.1	3.4	42.4	0.2	79.1	79.3		9.1	9.3

(a) previously recorded measurements, h approximated

Table A-5.--continued

	RAW DATA - (9/92)				CALCULATIONS		ASSUME LANDFILL BOTTOM ELEVATION OELEV = 70.0 m.s.l		
							OELEV < or = LBELEV		
							YES	NO	
GAS VENT #	GAS VENT ELEVATION AT GRADE VELEV m.s.l (ft)	DEPTH OF GAS VENT ABOVE GRADE h (ft)	AVERAGE DEPTH TO OBSTRUCTION DTO (ft)	AVERAGE DEPTH OF LEACHATE DOL (ft)	GAS VENT OBSTRUCTION ELEVATION OELEV m.s.l (ft)	GAS VENT LEACHATE ELEVATION LELEV m.s.l (ft)	H = DOL H (ft)	H = DOL + x x (ft)	H (ft)
16	114.8	3.1	42.6	0.5	75.3	75.7		5.3	5.7
17	112.6	2.9	39.8	3.3	75.7	79.0		5.7	9.0
18	107.0	2.8	40.2	3.2	69.5	72.8	3.2		
19	109.9	3.0	44.0	0.6	68.9	69.4	0.6		
20	110.4	2.8	37.5	14.2	75.7	89.9		5.7	19.9
21	116.3	3.2	40.6	12.7	78.8	91.5		8.8	21.5
22	121.0	2.5	39.8	9.5	83.8	93.3		13.8	23.3
23	121.9	2.8	38.5	0.2	86.2	86.4		16.2	16.4
24	119.4	3.0	40.2	0.5	82.2	82.7		12.2	12.7
25	121.7	3.4	42.1	0.4	83.0	83.4		13.0	13.4
26	128.5	2.6	41.2	13.8	90.0	103.8		20.0	33.8
27	123.7	3.4	39.8	0.0	87.3	87.3		17.3	0.0
28	128.4	3.3	41.9	8.3	89.7	98.1		19.7	28.1
29	123.3	3.1	42.0	0.4	84.3	84.7		14.3	14.7
30	124.2	3.3	45.5	16.3	82.0	98.3		12.0	28.3

(a) previously recorded measurements, h approximated

Table A-5.--continued

	RAW DATA - (9/92)				CALCULATIONS		ASSUME LANDFILL BOTTOM ELEVATION		
							OELEV = 70.0 m.s.1		
							OELEV < or = LBELEV		
GAS VENT #	GAS VENT ELEVATION AT GRADE VELEV m.s.1 (ft)	DEPTH OF GAS VENT ABOVE GRADE h (ft)	AVERAGE DEPTH TO OBSTRUCTION DTO (ft)	AVERAGE DEPTH OF LEACHATE DOL (ft)	GAS VENT OBSTRUCTION ELEVATION OELEV m.s.1 (ft)	GAS VENT LEACHATE ELEVATION LELEV m.s.1 (ft)	YES H = DOL H (ft)	NO H = DOL + x x (ft)	NO H = DOL + x H (ft)
31	120.5	3.3	39.9	6.3	83.9	90.2		13.9	20.2
32	113.0	2.8	37.8	12.4	78.1	90.5		8.1	20.5
33	124.1	2.9	51.2	20.5	75.8	96.3		5.8	26.3
34	128.8	3.3	68.4	0.1	63.8	63.8	0.1		
35	110.9	3.4	42.1	0.1	72.1	72.2		2.1	2.2
36	128.3	2.8	64.8	0.1	66.3	66.5	0.1		
37	131.6	2.9	29.4	3.6	105.2	108.8		35.2	38.8
38	136.1	2.6	27.0	0.0	111.7	111.7		41.7	0.0
39	138.1	2.4	32.5	15.5	107.9	123.4		37.9	53.4
40	136.0	2.8	52.3	1.4	86.5	87.9		16.5	17.9
41	128.6	2.3	27.3	5.8	103.7	109.5		33.7	39.5
42	129.6	3.2	46.9	0.5	85.9	86.4		15.9	16.4
43	123.8	2.5	34.9	0.0	91.4	91.4		21.4	0.0
44 (a)	123.0	2.5	55.0	0.0	70.5	70.5		0.5	0.0
46 (a)	120.5	2.5	52.5	0.0	70.5	70.5		0.5	0.0

(a) previously recorded measurements, h approximated

Table A-5.--continued

	RAW DATA - (9/92)				CALCULATIONS		ASSUME LANDFILL BOTTOM ELEVATION		
							OELEV = 70.0 m.s.1 OELEV < or = LBELEV		
							YES	NO	
							H = DOL	H = DOL + x	
GAS VENT #	GAS VENT ELEVATION AT GRADE VELEV m.s.1 (ft)	DEPTH OF GAS VENT ABOVE GRADE h (ft)	AVERAGE DEPTH TO OBSTRUCTION DTO (ft)	AVERAGE DEPTH OF LEACHATE DOL (ft)	GAS VENT OBSTRUCTION ELEVATION OELEV m.s.1 (ft)	GAS VENT LEACHATE ELEVATION LELEV m.s.1 (ft)	H (ft)	x (ft)	H (ft)
48 (a)	128.5	2.5	33.8	0.0	97.2	97.2		27.2	0.0
50 (a)	132.0	2.5	62.7	0.0	71.9	71.9		1.8	0.0
52	126.2	2.9	50.4	4.1	78.7	82.8		8.7	12.8
54	122.6	2.8	39.3	0.0	86.1	86.1		16.1	0.0
56	124.0	2.9	34.8	0.0	92.1	92.1		22.1	0.0

(a) previously recorded measurements, h approximated

APPENDIX B
ACSWL PVC SLUG TESTS RAW DATA AND CALCULATIONS

Figure B-1. PVC Slug Test Results--Head Versus Time

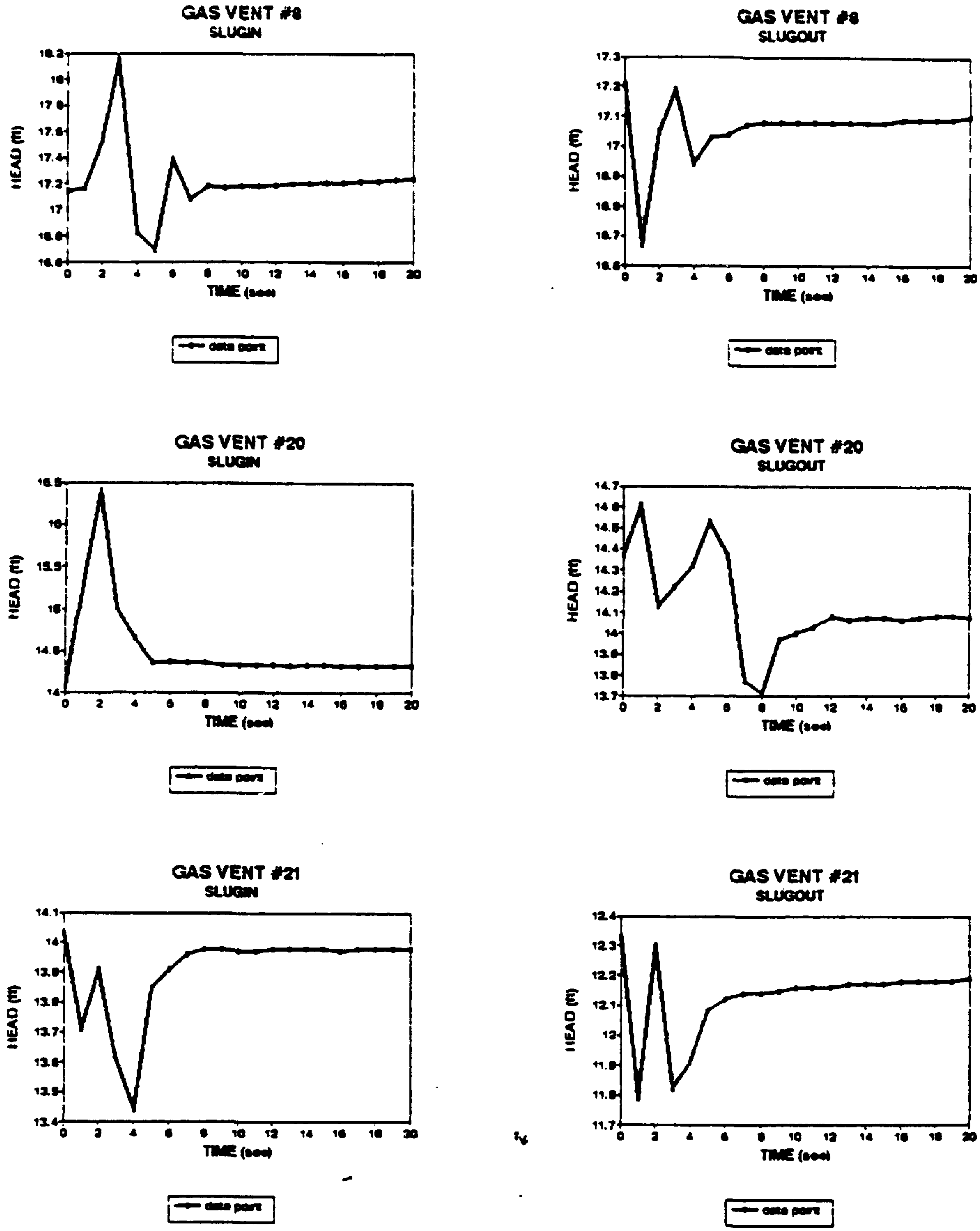


Figure B-1.--continued

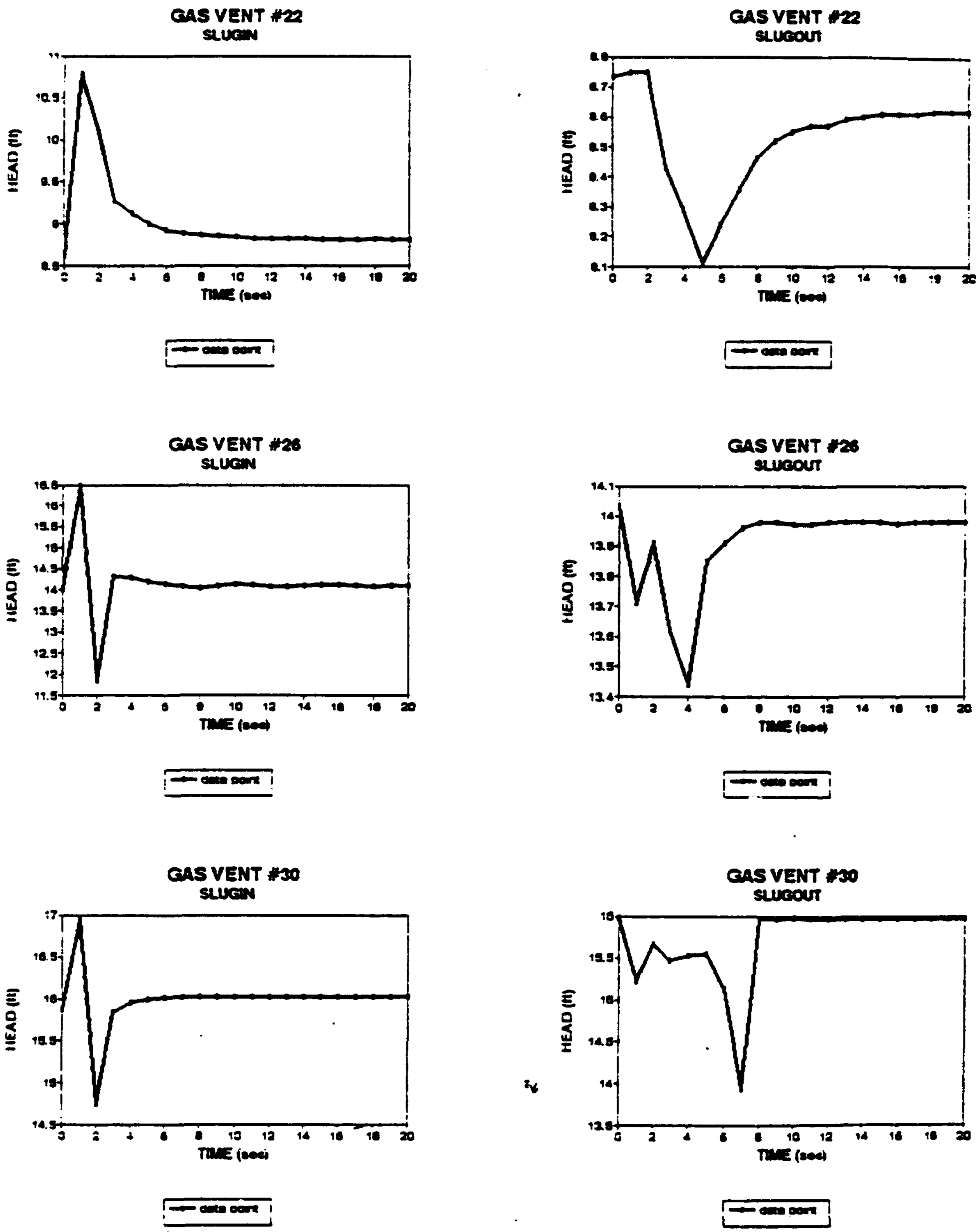
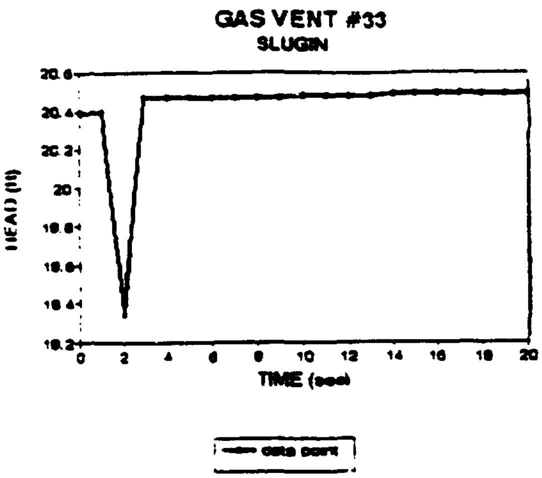


Figure B-1.--continued



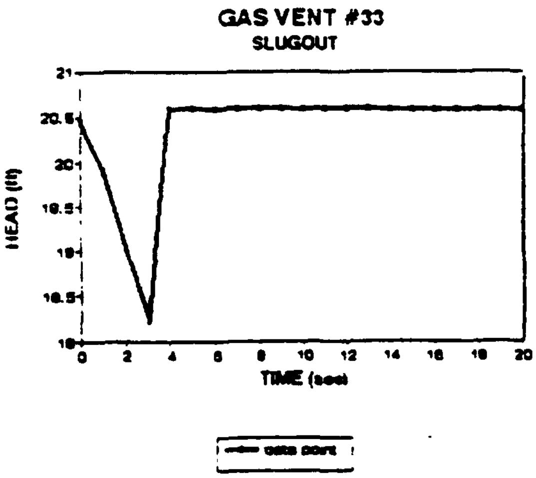


Table B-1. PVC Slug Test Calculations

GAS VENT # 8: 8PVCSLUGIN & 8PVCSLUGOUT ANALYSIS
Bouwer and Rice Method (Bouwer and Rice, 1976)
Date of Test: 7/92

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	35.00	ft
Leachate depth in Gas Vent (Lw) =	17.14	ft
Saturated thickness of Landfill (H) =	17.14	ft
gas vent elevation (msl) (05/92)	103.18	ft
assumed landfill bottom elevation (msl)	65.08	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Fully Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

Empirical constants:

where Le =	Partially Penetrating w	therefore
	A = 2.6	ln(Re/rw) =
35.00	B = 0.4	2.69
	Fully Penetrating wells	
	C = 2.2	

LINEAR REGRESSION
The linear portion of the semilog plot was selected.
Generally the first 1-3 seconds were disregarded.

8PVCSLUGIN		8PVCSLUGOUT	
LINEAR RANGE: 3 to 9 sec		LINEAR RANGE: 4 to 9 sec	
Regression Output:		Regression Output:	
Constant	0.87	Constant	-0.3
Std Err of Y Est	0.14	Std Err of Y Est	0.05
R Squared	0.98	R Squared	0.90
No. of Observations	4	No. of Observations	5
Degrees of Freedom	2	Degrees of Freedom	3
X Coefficient(s)	-0.268	X Coefficient(s)	-0.074
Std Err of Coef.	0.030	Std Err of Coef.	0.014

Table B-1.--continued

GAS VENT # 8: 8PVCSLUGIN & 8PVCSLUGOUT ANALYSIS (CONTINUED)

Compute slope of regressed line

8PVCSLUGIN t (sec)	8PVCSLUGIN y (ft)	8PVCSLUGOUT t (sec)	8PVCSLUGOUT y (ft)
0	0.87	0	-0.32
1.0	0.60	1.0	-0.39

Calculation of Hydraulic Conductivity:

8PVCSLUGIN		8PVCSLUGOUT	
K =	4.90E-03 ft/min	K =	2.772E-03 ft/min
K =	2.49E-03 cm/sec	K =	1.408E-03 cm/sec

Effective Volume of Leachate Displaced:

8PVCSLUGIN		8PVCSLUGOUT	
volume in gas vent		volume in gas vent	
y(3) - y(9)	0.3400 ft	y(4) - y(8	0.0500 ft
	0.07 ft^3		0.01 ft^3
volume in borehole		volume in borehole	
	0.07 ft^3		0.01 ft^3
height in borehole		height in borehole	
(gravel pack n = 0.30)		(gravel pack n = 0.30)	
	0.06 ft		0.01 ft

Table B-1.--continued

GAS VENT # 20: 20PVCSLUGIN & 20PVCSLUGOUT ANALYSIS

Bouwer and Rice ethod (Bouwer and Rice, 1976)

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	20.00	ft
Leachate depth in Gas Vent (Lw) =	14.07	ft
Saturated thickness of Landfill (H) =	16.19	ft
gas vent elevation (msl) (05/92)	110.42	ft
assumed landfill bottom elevation (msl)	70.00	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Partially Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

Empirical constants:

	Partially Penetrating wells:		therefore
where Le =	A =	2.25	ln(Re/rw) =
20.00	B =	0.6	1.81
	Fully Penetrating wells:		
	C =	1.75	

LINEAR REGRESSION
The linear portion of the semilog plot was selected.
Generally the first 1-3 seconds were disregarded.

20PVCSLUGIN
LINEAR RANGE: 2 to 5 sec

Regression Output:		
Constant		0.92
Std Err of Y Est		0.05
R Squared		0.39
No. of Observations		4
Degrees of Freedom		2
X Coefficient(s)	-0.293	
Std Err of Coef.	0.024	

20PVCSLUGOUT
LINEAR RANGE: 7 to 12 sec

Regression Outpu		
Constant		0.30
Std Err of Y Est		0.06
R Squared		0.87
No. of Observations		6
Degrees of Freedom	-0.071	4
Std Err of Coef.	0.0134	
X Coefficient(s)	-0.071	
Std Err of Coef.	0.013	

Table B-1.--continued

GAS VENT # 20: 20PVCSLUGIN & 20PVCSLUGOUT ANALYSIS (CONTINUED)

Compute slope of regressed line

t (sec)	y (ft)	t (sec)	y (ft)
0	0.92	0	0.30
1.0	0.63	1.0	0.23

Calculation of Hydraulic Conductivity:

K =	5.98E-03 ft/min	K =	4.208E-03 ft/min
K =	3.04E-03 cm/sec	K =	2.137E-03 cm/sec

Effective Volume of Leachate Displace

volume in gas vent			volume in gas vent		
y(2) - y(5	2.0500	ft	y(5) - y(12	0.4500	ft
	0.40	ft^3		0.09	ft^3
volume in borehole			volume in borehole		
	0.40	ft^3		0.09	ft^3
height in borehole			height in borehole		
(gravel pack n = 0.30)			(gravel pack n = 0.30)		
	0.37	ft		0.08	ft

Table B-1.--continued

GAS VENT #21: 21PVCSLUGIN & 21PVCSLUGOUT ANALYSIS

Bouwer and Rice Method (Bouwer and Rice, 1976)
Date of Test: 7/92

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	20.00	ft
Leachate depth in Gas Vent (Lw) =	12.33	ft
Saturated thickness of Landfill (H) =	21.20	ft
gas vent elevation (msl) (05/92)	116.30	ft
assumed landfill bottom elevation (msl)	70.00	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Partially Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

Empirical constants:

	Partially Penetrating wells:		therefore	
where Le =	A =	2.25	ln(Re/rw) =	
20.00	B =	0.6		1.62
	Fully Penetrating wells:			
	C =	1.75		

LINEAR REGRESSION
The linear portion of the semilog plot was selected.
Generally the first 1-3 seconds were disregarded.

21PVCSLUGIN
LINEAR RANGE: 2 to 6 sec

Regression Output:		
Constant		0.23
Std Err of Y Est		0.31
R Squared		0.64
No. of Observations		5
Degrees of Freedom		3
X Coefficient(s)	-0.225	
Std Err of Coef.	0.097	

21PVCSLUGOUT
LINEAR RANGE: 4 to 9 sec

Regression Outpu		
Constant		0.0
Std Err of Y Est		0.06
R Squared		0.94
No. of Observations		5
Degrees of Freedom	-0.071	3
Std Err of Coef.	0.0134	
X Coefficient(s)	-0.116	
Std Err of Coef.	0.018	

Table B-1.--continued

GAS VENT #21: 21PVCSLUGIN & 21PVCSLUGOUT ANALYSIS (CONTINUED)

21PVCSLUGIN

Compute slope of regressed line

t (sec)	y (ft)
2	-0.22
3.0	-0.44

21PVCSLUGOUT

t (sec)	y (ft)
1	-0.07
2.0	-0.19

Calculation of Hydraulic Conductivity:

21PVCSLUGIN

K = 6.58E-03 ft/min
K = 3.34E-03 cm/sec

21PVCSLUGOUT

K = 6.777E-03 ft/min
K = 3.443E-03 cm/sec

Effective Volume of Leachate Displace

21PVCSLUGIN

Max volume displaced in gas vent
1.1600 ft
0.23 ft^3
volume in borehole
0.23 ft^3
height in borehole
(gravel pack n = 0.30)
0.21 ft

21PVCSLUGOUT

Max volume displaced
0.5400 ft
0.11 ft^3
volume in borehole
0.11 ft^3
height in borehole
(gravel pack n = 0.30)
0.10 ft

Table B-1.--continued

GAS VENT #22: 22PVCSLUGIN & 22PVCSLUGOUT ANALYSIS

Bouwer and Rice Method (Bouwer and Rice, 1976)
Date of Test: 7/92

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	35.00	ft
Leachate depth in Gas Vent (Lw) =	8.62	ft
Saturated thickness of Landfill (H) =	22.40	ft
gas vent elevation (msl) (05/92)	121.04	ft
assumed landfill bottom elevation (msl)	70.00	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Partially Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

Empirical constants:

		Partially Penetrating wells:		therefore
where Le =		A =	2.6	ln(Re/rw) =
	35.00	B =	0.4	1.63
		Fully Penetrating wells:		
		C =	2.2	

LINEAR REGRESSION
The linear portion of the semilog plot was selected.
Generally the first 1-3 seconds were disregarded.

22PVCSLUGIN
LINEAR RANGE: 2 to 6 sec

Regression Output:		
Constant		0.01
Std Err of Y Est		0.02
R Squared		0.99
No. of Observations		5
Degrees of Freedom		3
X Coefficient(s)	-0.103	
Std Err of Coef.	0.007	

22PVCSLUGOUT
LINEAR RANGE: 6 to 11 sec

Regression Outpu		
Constant		0.3
Std Err of Y Est		0.03
R Squared		0.98
No. of Observations		7
Degrees of Freedom	-0.071	5
Std Err of Coef.	0.0134	
X Coefficient(s)	-0.103	
Std Err of Coef.	0.006	

Table B-1.--continued

GAS VENT #22: 22PVCSLUGIN & 22PVCSLUGOUT ANALYSIS (CONTINUED)

22PVCSLUGIN

Compute slope of regressed line

t (sec)	y (ft)
1	-0.09
2.0	-0.20

22PVCSLUGOUT

t (sec)	y (ft)
1	0.19
2.0	0.08

Calculation of Hydraulic Conductivity:

22PVCSLUGIN

K = 2.99E-03 ft/min
K = 1.52E-03 cm/sec

22PVCSLUGOUT

K = 3.205E-03 ft/min
K = 1.628E-03 cm/sec

Effective Volume of Leachate Displace

22PVCSLUGIN

Max volume displaced in gas vent
2.1700 ft
0.43 ft^3
volume in borehole
0.43 ft^3
height in borehole
(gravel pack n = 0.30)
0.39 ft

22PVCSLUGOUT

Max volume displaced
0.6200 ft
0.12 ft^3
volume in borehole
0.12 ft^3
height in borehole
(gravel pack n = 0.30)
0.11 ft

Table B-1.--continued

GAS VENT # 26: 26PVCSLUGIN & 26PVCSLUGOUT ANALYSIS

Bouwer and Rice ethod (Bouwer and Rice, 1976)
Date of Test 7/92

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	20.00	ft
Leachate depth in Gas Vent (Lw) =	14.03	ft
Saturated thickness of Landfill (H) =	33.95	ft
gas vent elevation (msl) (05/92)	128.49	ft
assumed landfill bottom elevation (msl)	70.00	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Partially Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

Empirical constants:

	Partially Penetrating wells:		therefore
where Le =	A =	2.25	ln(Re/rw) =
20.00	B =	0.6	1.62
	Fully Penetrating wells:		
	C =	1.75	

LINEAR REGRESSION
The linear portion of the semilog plot was selected.
Generally the first 1-3 seconds were disregarded.

26PVCSLUGIN
LINEAR RANGE: 2 to 8 sec

Regression Output:	
Constant	-0.37
Std Err of Y Est	0.41
R Squared	0.39
No. of Observations	8
Degrees of Freedom	6
X Coefficient(s)	-0.123
Std Err of Coef.	0.063

26PVCSLUGOUT
LINEAR RANGE: 4 to 9 sec

Regression Output:	
Constant	0.40
Std Err of Y Est	0.16
R Squared	0.89
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.207
Std Err of Coef.	0.037

Table B-1.--continued

GAS VENT # 26: 26PVCSLUGIN & 26PVCSLUGOUT ANALYSIS (CONTINUED)

Compute slope of regressed line

t (sec)	y (ft)	t (sec)	y (ft)
2	-0.61	2	-0.01
3.0	-0.74	3.0	-0.22

Calculation of Hydraulic Conductivity:

K =	1.69E-03 ft/min	K =	3.027E-02 ft/min
K =	8.61E-04 cm/sec	K =	1.538E-02 cm/sec

Effective Volume of Leachate Displace

volume in gas vent		volume in gas vent	
	2.4700 ft		0.5900 ft
	0.48 ft^3		0.12 ft^3
volume in borehole		volume in borehole	
	0.48 ft^3		0.12 ft^3
height in borehole (gravel pack n = 0.30)		height in borehole (gravel pack n = 0.30)	
	0.45 ft		0.11 ft

Table B-1.--continued

GAS VENT # 30: 30PVCSLUGIN & 30PVCSLUGOUT ANALYSIS

Bouwer and Rice ethod (Bouwer and Rice, 1976)
Date of Test 7/92

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	35.00	ft
Leachate depth in Gas Vent (Lw) =	15.88	ft
Saturated thickness of Landfill (H) =	27.88	ft
gas vent elevation (msl) (05/92)	124.21	ft
assumed landfill bottom elevation (msl)	70.00	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Partially Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

Empirical constants:

	Partially Penetrating wells:		therefore
where Le =	A =	2.6	ln(Re/rw) =
35.00	B =	0.4	2.00
	Fully Penetrating wells:		
	C =	2.2	

LINEAR REGRESSION

No analysis, no linear trend in the semilog plot

Table B-1.--continued

GAS VENT # 33: 33PVCSLUGIN & 33PVCSLUGOUT ANALYSIS

Bouwer and Rice ethod (Bouwer and Rice, 1976)
Date of Test 7/92

GAS VENT DESCRIPTION		
Gas Vent casing diameter (2rc) =	0.50	ft
Gas Vent Borehole diameter (2rw) =	2.00	ft
Length of Gas Vent Perforated Section (Le) =	35.00	ft
Leachate depth in Gas Vent (Lw) =	20.39	ft
Saturated thickness of Landfill (H) =	26.20	ft
gas vent elevation (msl) (05/92)	124.07	ft
assumed landfill bottom elevation (msl)	70.00	ft
assumed gravel pack porosity, n	0.30	
Gas Vent Type: Partially Penetrating		

CALCULATIONS
Adjustment for rc due to gravel envelope:
This calculation is based on the total free-water surface area in gas vent and gravel pack where n is the porosity, and (rw-rc) is the thickness of the gravel pack (envelope).

Adjusted rc: 0.586 ft

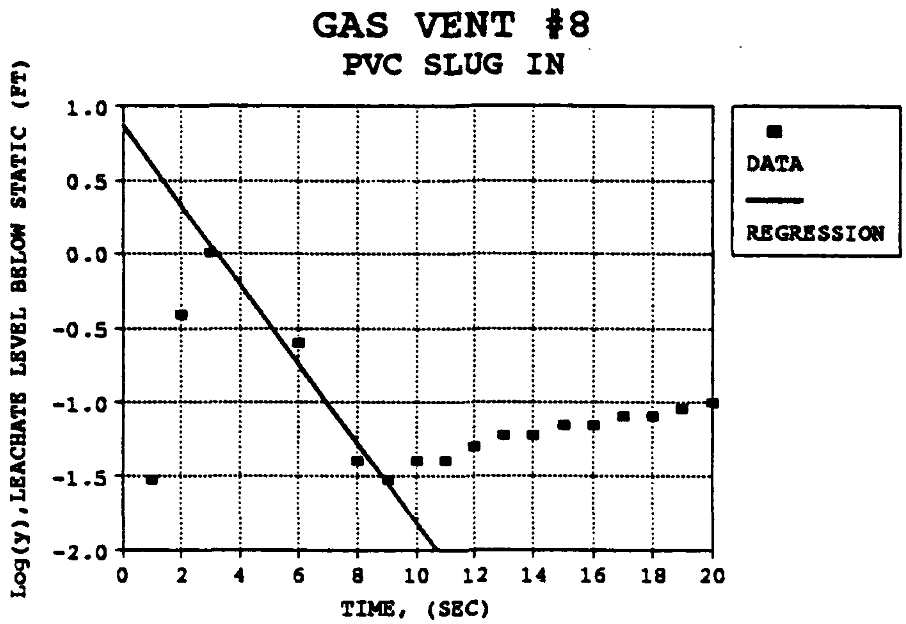
Empirical constants:

	Partially Penetrating wells:		therefore
where Le =	A =	2.6	ln(Re/rw) =
35.00	B =	0.4	2.18
	Fully Penetrating wells:		
	C =	2.2	

LINEAR REGRESSION

No analysis, gas vent was not responsive to the injection or withdrawal of a slug

Figure B-2. PVC Slug Test Semilog Plots



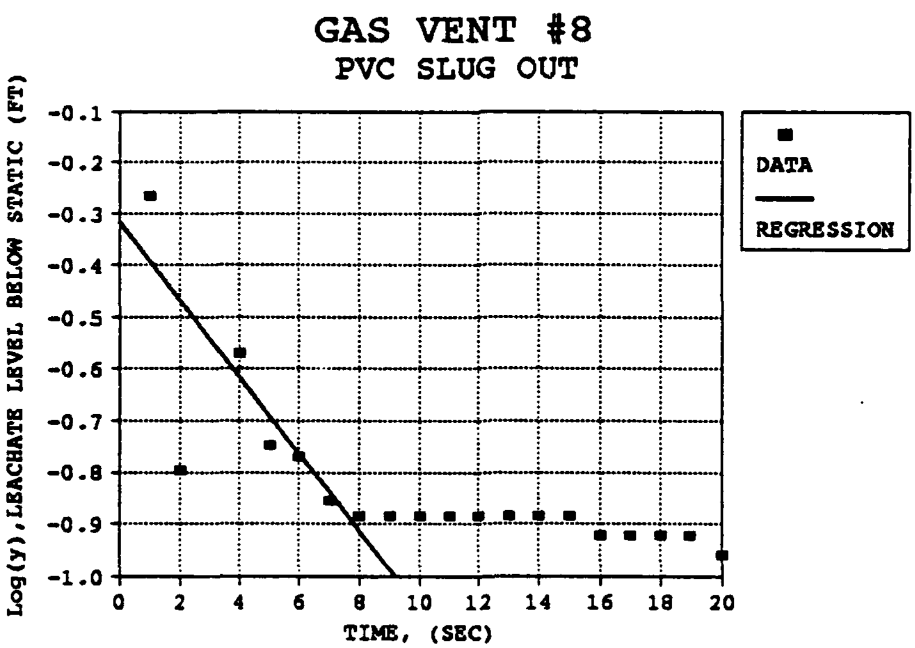
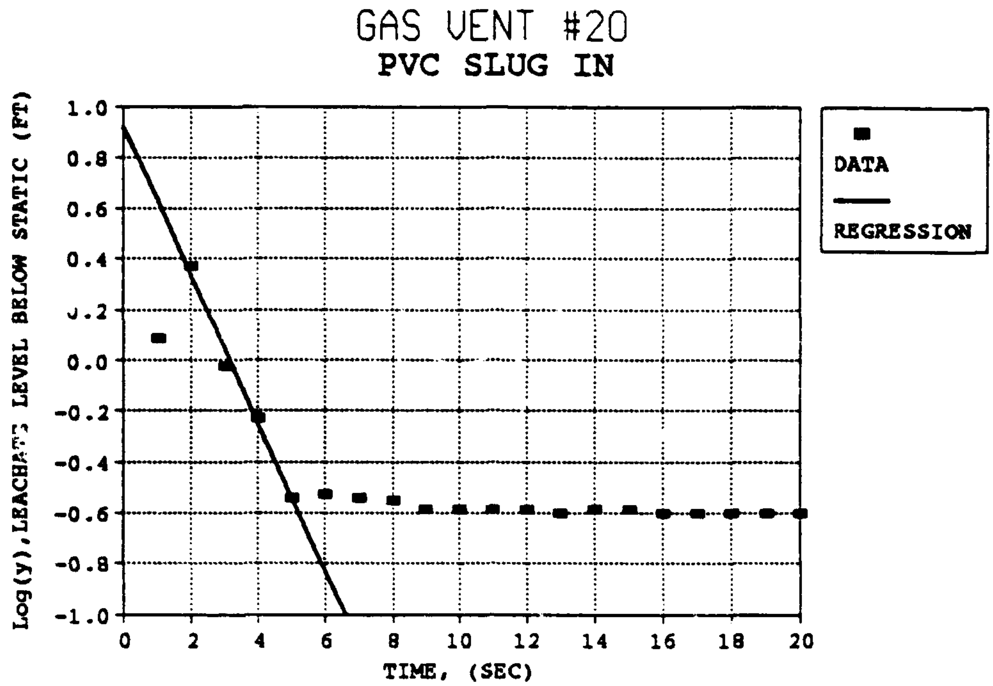


Figure B-2.--continued



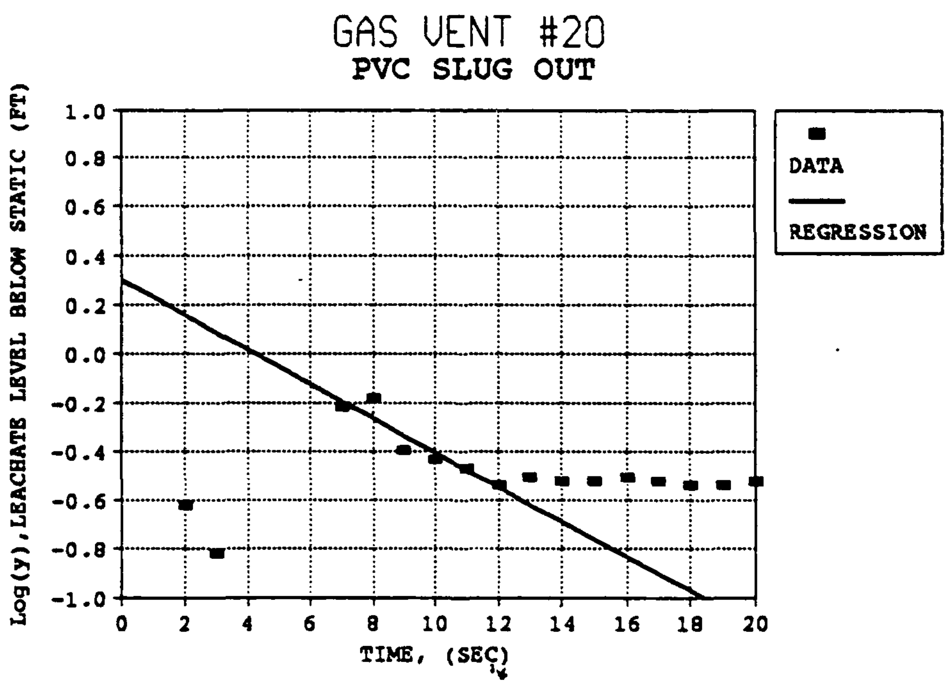
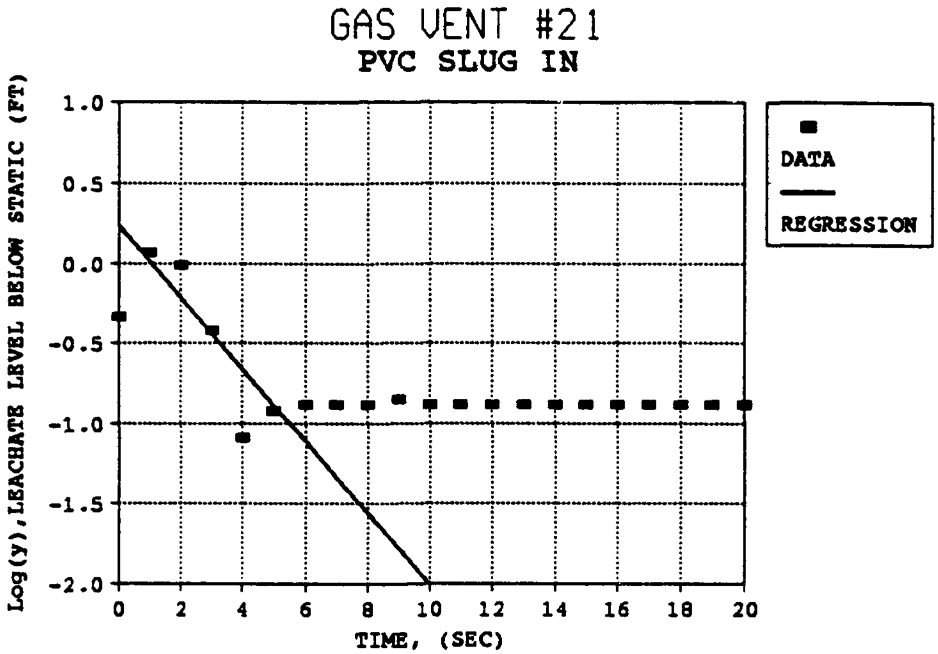


Figure B-2.--continued



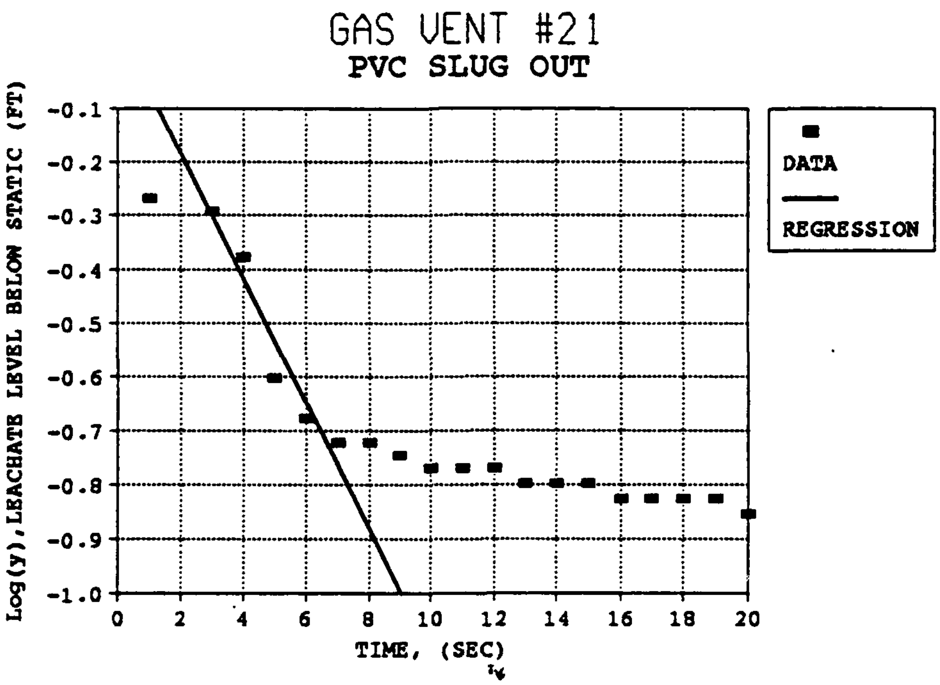
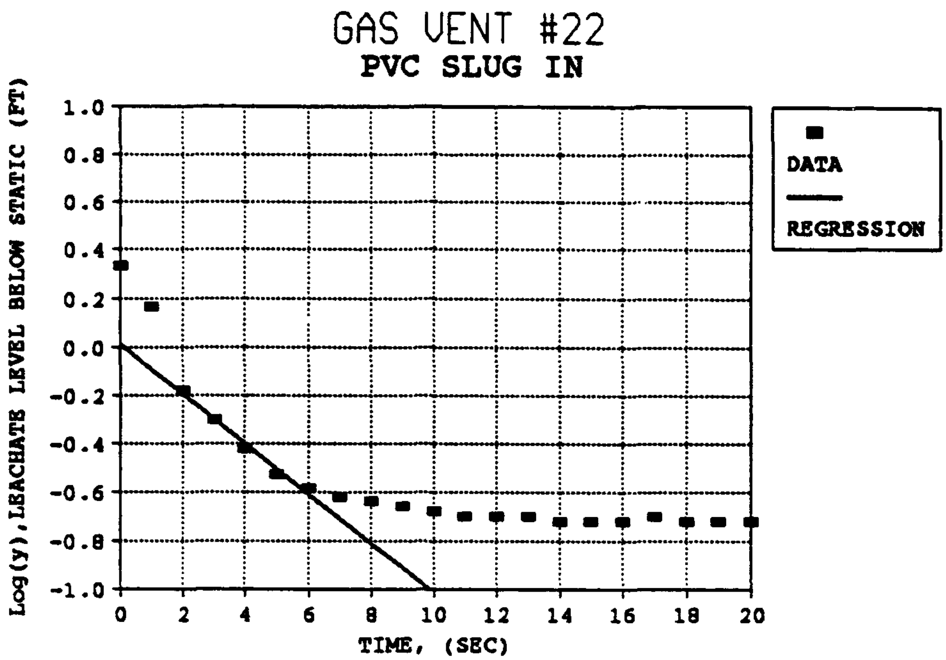


Figure B-2.--continued



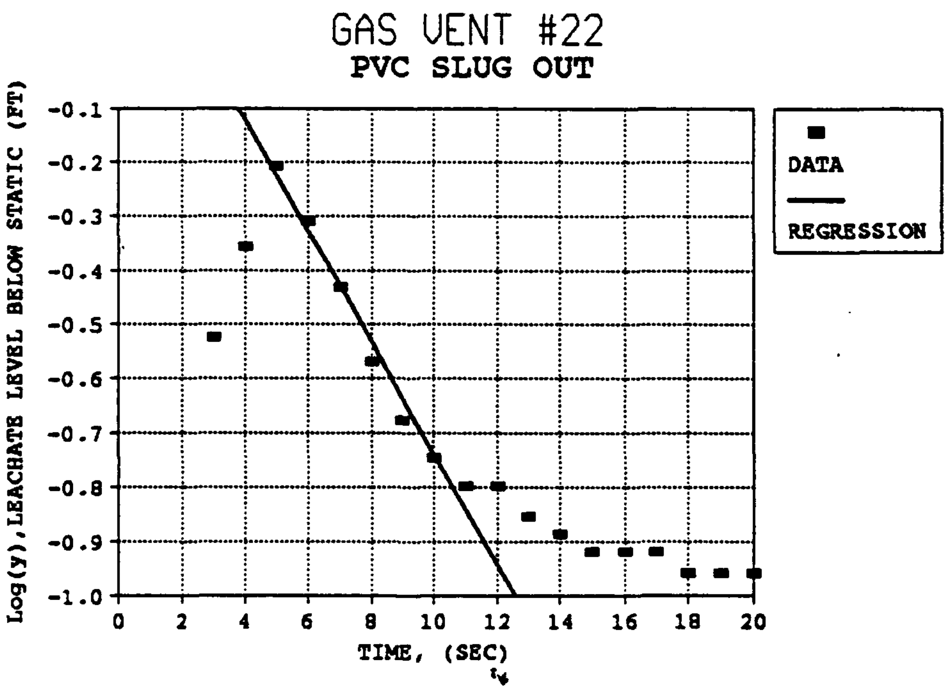
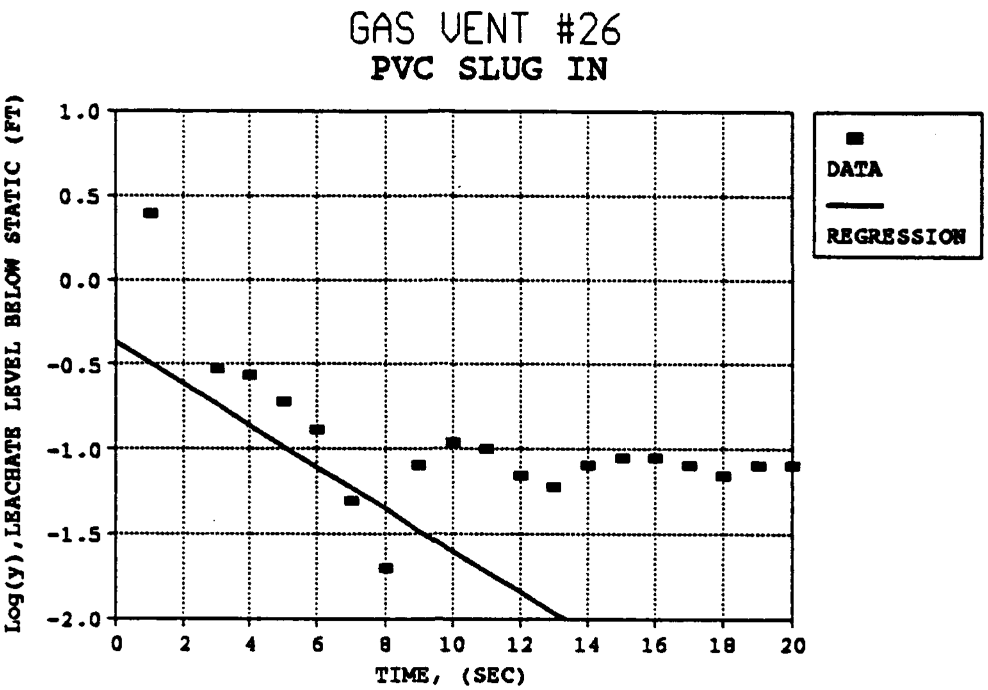


Figure B-2.--continued



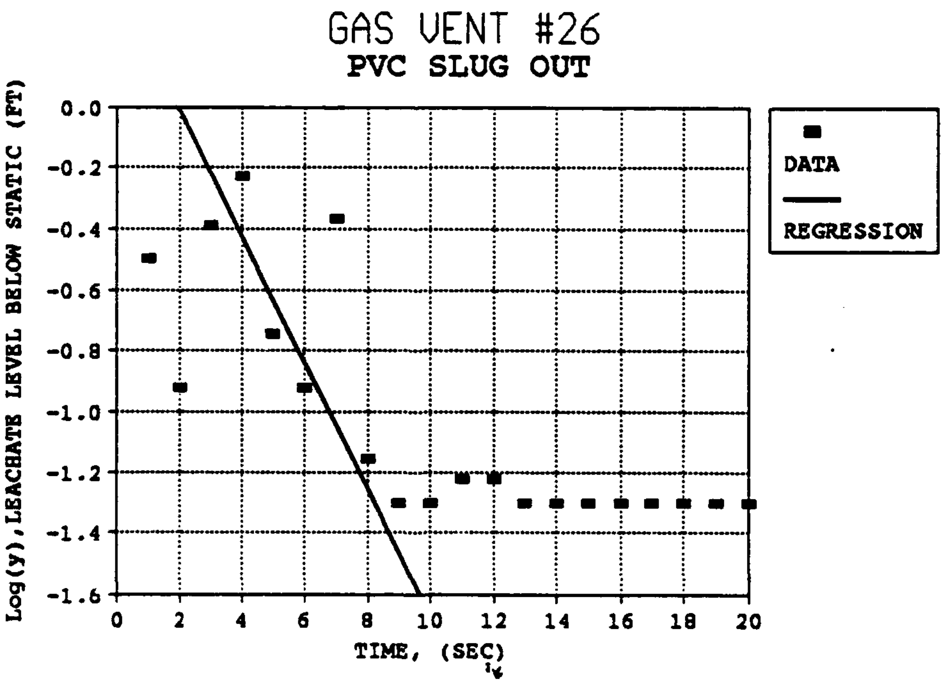
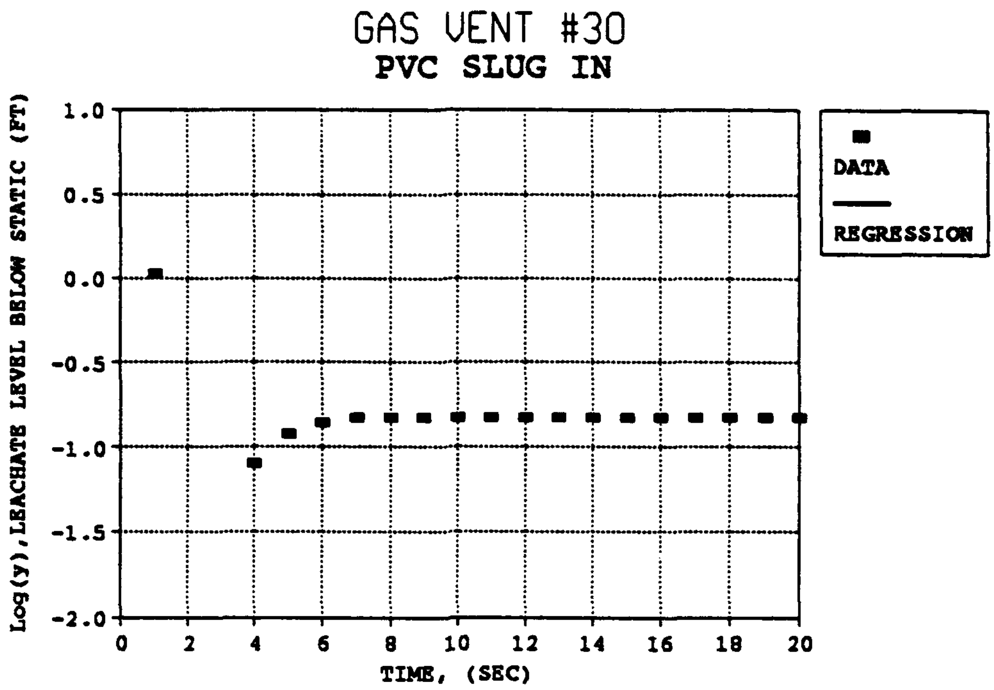


Figure B-2.--continued



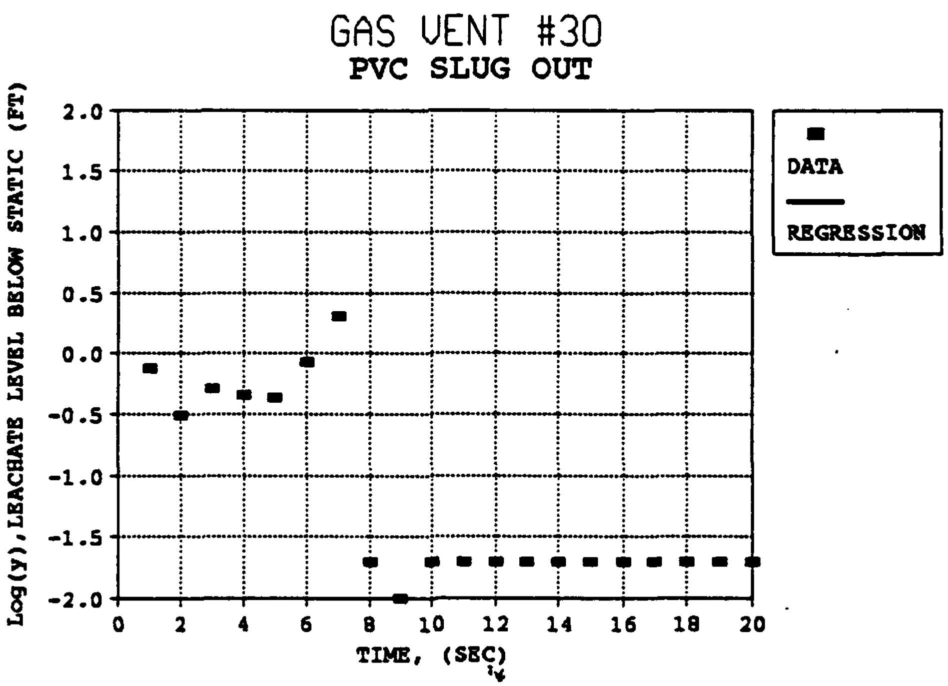
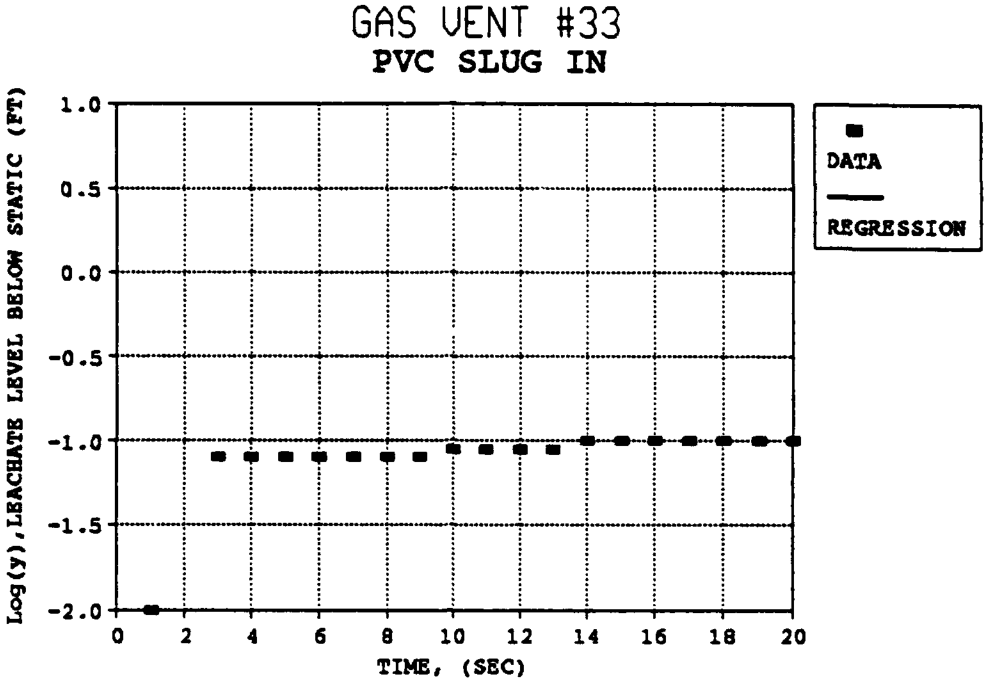


Figure B-2.--continued



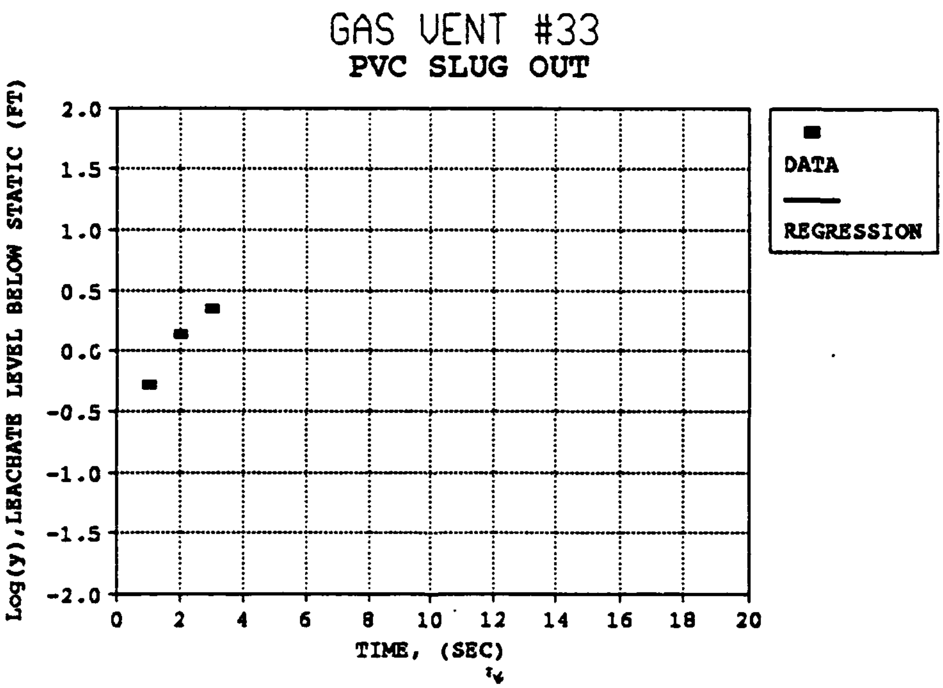


Table B-2. PVC Slug Test Raw Data

8PVCSLUGIN			RAW DATA	8PVCSLUGOUT			RAW DATA
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
17.14	0	17.26	41	17.21	0	17.10	41
17.17	1	17.26	42	16.67	1	17.10	42
17.53	2	17.26	43	17.05	2	17.10	43
18.16	3	17.26	44	17.19	3	17.10	44
16.83	4	17.26	45	16.94	4	17.10	45
16.69	5	17.26	46	17.03	5	17.10	46
17.39	6	17.26	47	17.04	6	17.10	47
17.08	7	17.26	48	17.07	7	17.10	48
17.18	8	17.26	49	17.08	8	17.10	49
17.17	9	17.26	50	17.08	9	17.10	50
17.18	10	17.26	51	17.08	10	17.10	51
17.18	11	17.26	52	17.08	11	17.10	52
17.19	12	17.25	72	17.08	12	17.10	53
17.20	13	17.25	92	17.08	13	17.10	54
17.20	14	17.25	112	17.08	14	17.10	74
17.21	15	17.24	132	17.08	15	17.10	94
17.21	16	17.24	152	17.09	16	17.10	114
17.22	17	17.24	172	17.09	17	17.10	134
17.22	18	17.24	192	17.09	18	17.09	154
17.23	19	17.23	212	17.09	19	17.09	174
17.24	20	17.23	232	17.10	20	17.10	194
17.24	21	17.23	252	17.09	21	17.10	214
17.25	22	17.23	272	17.09	22	17.09	234
17.25	23	17.24	292	17.09	23	17.09	254
17.25	24	17.22	322	17.10	24	17.09	274
17.25	25	17.22	352	17.10	25	17.09	304
17.25	26	17.22	382	17.10	26	17.09	334
17.25	27	17.22	412	17.10	27	17.09	364
17.26	28	17.22	442	17.10	28	17.09	394
17.26	29	17.22	472	17.10	29		
17.26	30	17.22	502	17.10	30		
17.26	31			17.10	31		
17.26	32			17.10	32		
17.26	33			17.10	33		
17.26	34			17.10	34		
17.26	35			17.10	35		
17.26	36			17.10	36		
17.26	37			17.10	37		
17.26	38			17.10	38		
17.2[illegible]	39			17.10	39		
17.26	40			17.10	40		

Table B-2.--continued

20PVCSLUGIN		RAW DATA		20PVCSLUGOUT		RAW DATA	
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
14.07	0	14.32	41	14.37	0	14.07	41
15.30	1	14.32	42	14.61	1	14.07	42
16.41	2	14.32	43	14.13	2	14.07	43
15.02	3	14.32	44	14.22	3	14.07	44
14.66	4	14.32	45	14.32	4	14.07	45
14.36	5	14.32	46	14.53	5	14.07	46
14.37	6	14.32	47	14.37	6	14.07	47
14.36	7	14.32	48	13.77	7	14.07	48
14.35	8	14.32	49	13.71	8	14.07	49
14.33	9	14.32	50	13.97	9	14.07	50
14.33	10	14.32	51	14.00	10	14.07	51
14.33	11	14.32	52	14.03	11	14.07	52
14.33	12	14.32	53	14.08	12	14.07	53
14.32	13	14.32	54	14.06	13	14.07	54
14.33	14	14.32	55	14.07	14	14.07	55
14.33	15	14.33	75	14.07	15	14.07	56
14.32	16	14.33	95	14.06	16	14.07	57
14.32	17	14.33	115	14.07	17	14.07	58
14.32	18	14.34	135	14.08	18	14.07	59
14.32	19	14.34	155	14.08	19	14.07	60
14.32	20	14.34	175	14.07	20	14.07	80
14.32	21	14.52	195	14.09	21	14.07	100
14.32	22	14.35	215	14.09	22	14.07	120
14.32	23	14.36	235	14.08	23	14.07	140
14.32	24	14.36	255	14.07	24		
14.32	25	14.37	275	14.06	25		
14.32	26			14.07	26		
14.32	27			14.08	27		
14.32	28			14.08	28		
14.32	29			14.07	29		
14.32	30			14.09	30		
14.32	31			14.09	31		
14.32	32			14.08	32		
14.32	33			14.07	33		
14.32	34			14.07	34		
14.32	35			14.07	35		
14.32	36			14.07	36		
14.32	37			14.07	37		
14.32	38			14.07	38		
14.32	39			14.07	39		
14.32	40			14.07	40		

Table B-2.--continued

21PVCSLUGIN		RAW DATA		21PVCSLUGOUT		RAW DATA	
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
12.79	0	12.42	41	12.33	0	12.21	41
13.49	1	12.42	42	11.79	1	12.21	42
13.30	2	12.42	43	12.30	2	12.21	43
12.71	3	12.42	44	11.82	3	12.21	44
12.41	4	12.42	45	11.91	4	12.21	45
12.45	5	12.42	46	12.08	5	12.21	46
12.46	6	12.41	47	12.12	6	12.21	47
12.46	7	12.41	48	12.14	7	12.21	48
12.46	8	12.41	49	12.14	8	12.21	49
12.47	9	12.41	50	12.15	9	12.21	50
12.46	10	12.41	51	12.16	10	12.21	51
12.46	11	12.41	52	12.16	11	12.21	52
12.46	12	12.41	53	12.16	12	12.21	53
12.46	13	12.41	54	12.17	13	12.21	54
12.46	14	12.41	55	12.17	14	12.21	55
12.46	15	12.40	56	12.17	15	12.21	56
12.46	16	12.40	57	12.18	16	12.22	76
12.46	17	12.40	58	12.18	17	12.23	96
12.46	18	12.40	59	12.18	18	12.24	116
12.46	19	12.40	60	12.18	19	12.25	136
12.46	20	12.40	80	12.19	20	12.26	156
12.45	21	12.39	100	12.19	21	12.27	176
12.45	22	12.39	120	12.19	22	12.28	196
12.45	23	12.38	140	12.19	23	12.28	216
12.45	24	12.37	160	12.19	24	12.28	236
12.45	25	12.37	180	12.19	25	12.28	256
12.44	26	12.36	200	12.19	26	12.28	276
12.44	27	12.35	220	12.20	27	12.28	296
12.44	28	12.35	240	12.20	28	12.28	326
12.44	29	12.35	260	12.20	29	12.29	356
12.44	30	12.34	280	12.20	30	12.30	386
12.44	31	12.34	300	12.20	31	12.30	416
12.43	32	12.34	320	12.20	32	12.31	446
12.43	33	12.34	340	12.20	33	12.31	476
12.43	34	12.34	360	12.20	34	12.31	506
12.43	35	12.34	390	12.21	35	12.31	536
12.43	36	12.34	420	12.21	36	12.31	566
12.43	37	12.33	450	12.21	37		
12.43	38	12.33	480	12.21	38		
12.42	39	12.33	510	12.21	39		
12.42	40			12.21	40		

Table B-2.--continued

22PVCSLUGIN		RAW DATA		22PVCSLUGOUT		RAW DATA	
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
8.62	0	8.79	41	8.73	0	8.63	41
10.79	1	8.79	42	8.75	1	8.63	42
10.09	2	8.79	43	8.73	2	8.63	43
9.28	3	8.79	44	8.43	3	8.63	44
9.12	4	8.79	45	8.29	4	8.63	45
9.00	5	8.78	46	8.11	5	8.63	46
8.92	6	8.78	47	8.24	6	8.63	47
8.88	7	8.78	48	8.36	7	8.63	48
8.86	8	8.78	49	8.46	8	8.63	49
8.85	9	8.78	50	8.52	9	8.63	50
8.84	10	8.78	51	8.55	10	8.63	51
8.83	11	8.78	52	8.57	11	8.63	52
8.82	12	8.78	53	8.57	12	8.63	53
8.82	13	8.77	54	8.59	13	8.63	54
8.82	14	8.79	74	8.60	14	8.63	55
8.81	15	8.76	94	8.61	15	8.64	75
8.81	16	8.78	114	8.61	16	8.65	95
8.81	17	8.75	134	8.61	17	8.65	115
8.82	18	8.75	154	8.62	18	8.65	135
8.81	19	8.75	174	8.62	19	8.65	155
8.81	20	8.75	194	8.62	20	8.66	175
8.81	21	8.75	214	8.62	21	8.67	195
8.81	22	8.75	234	8.62	22	8.67	215
8.81	23	8.75	254	8.62	23	8.67	235
8.81	24	8.75	274	8.62	24	8.67	255
8.81	25	8.75	294	8.62	25	8.67	275
8.81	26	8.75	314	8.62	26	8.68	295
8.80	27	8.75	334	8.62	27	8.68	315
8.80	28	8.75	354	8.62	28	8.68	335
8.80	29	8.74	384	8.62	29	8.68	355
8.79	30	8.74	414	8.62	30	8.68	385
8.79	31	8.74	444	8.63	31	8.68	415
8.79	32	8.74	474	8.63	32	8.68	445
8.79	33	8.73	504	8.63	33		
8.79	34			8.63	34		
8.79	35			8.63	35		
8.79	36			8.63	36		
8.79	37			8.63	37		
8.79	38			8.63	38		
8.79	39			8.63	39		
8.79	40			8.63	40		

Table B-2.--continued

26PVCSLUGIN		RAW DATA		26PVCSLUGOUT		RAW DATA	
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
14.02	0	14.08	41	14.03	0	13.98	41
16.50	1	14.08	42	13.71	1	13.97	42
11.85	2	14.08	43	13.91	2	13.97	43
14.32	3	14.08	44	13.62	3	13.97	44
14.29	4	14.08	45	13.44	4	13.97	45
14.21	5	14.08	46	13.85	5	13.97	65
14.15	6	14.08	47	13.91	6	13.97	85
14.07	7	14.08	48	13.96	7	13.97	105
14.04	8	14.08	49	13.98	8	13.97	125
14.10	9	14.08	50	13.98	9	13.97	165
14.13	10	14.08	51	13.97	10	13.97	185
14.12	11	14.08	52	13.97	11	13.97	205
14.09	12	14.07	53	13.98	12	13.97	225
14.08	13	14.07	54	13.98	13	13.97	245
14.10	14	14.07	74	13.98	14	13.96	265
14.11	15	14.07	94	13.98	15	13.96	285
14.11	16	14.07	114	13.97	16	13.96	315
14.10	17	14.07	134	13.98	17	13.96	345
14.09	18	14.06	154	13.98	18	13.96	375
14.10	19	14.06	174	13.98	19	13.96	405
14.10	20	14.06	194	13.98	20	13.96	435
14.09	21	14.06	214	13.98	21	13.96	465
14.09	22	14.06	234	13.98	22	13.96	495
14.09	23	14.06	254	13.98	23	13.96	525
14.09	24	14.06	274	13.98	24	13.96	555
14.09	25	14.05	294	13.98	25		
14.09	26	14.05	314	13.98	26		
14.09	27	14.05	334	13.98	27		
14.09	28	14.05	354	13.98	28		
14.09	29	14.05	384	13.98	29		
14.07	30	14.05	414	13.98	30		
14.10	31	14.05	444	13.98	31		
14.09	32	14.04	474	13.98	32		
14.09	33	14.04	504	13.97	33		
14.09	34			13.98	34		
14.09	35			13.98	35		
14.09	36			13.98	36		
14.09	37			13.98	37		
14.08	38			13.98	38		
14.09	39			13.98	39		
14.08	40			13.98	40		

Table B-2.--continued

30PVCSLUGIN		RAW DATA		30PVCSLUGOUT		RAW DATA	
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
15.88	0	16.02	41	15.98	0	15.95	41
16.95	1	16.02	42	15.22	1	15.95	42
14.75	2	16.02	43	15.67	2	15.95	43
15.84	3	16.02	44	15.47	3	15.95	44
15.96	4	16.02	45	15.53	4	15.95	45
16.00	5	16.02	46	15.55	5	15.95	46
16.02	6	16.02	47	15.13	6	15.95	47
16.03	7	16.02	48	13.93	7	15.95	48
16.03	8	16.02	49	15.96	8	15.95	49
16.03	9	16.02	50	15.96	9	15.95	50
16.03	10	16.02	51	15.97	10	15.95	51
16.03	11	16.02	52	15.96	11	15.95	52
16.03	12	16.01	53	15.96	12	15.95	53
16.03	13	16.01	54	15.96	13	15.95	54
16.03	14	16.01	74	15.96	14	15.95	55
16.03	15	16.01	94	15.96	15	15.95	75
16.03	16	16.01	114	15.96	16	15.95	95
16.03	17	16.01	134	15.96	17	15.95	115
16.03	18	16.01	154	15.96	18	15.96	135
16.03	19	16.01	174	15.96	19	15.96	175
16.03	20	15.99	194	15.96	20	15.96	195
16.03	21	15.99	214	15.96	21	15.96	215
16.03	22	15.99	234	15.96	22	15.96	235
16.03	23	15.99	254	15.95	23	15.96	255
16.03	24	15.99	274	15.95	24	15.96	275
16.03	25	15.99	294	15.95	25	15.96	295
16.03	26	15.99	324	15.95	26	15.96	325
16.03	27	15.99	354	15.95	27	15.96	355
16.02	28	15.99	384	15.95	28		
16.02	29	15.98	414	15.95	29		
16.02	30	15.98	444	15.95	30		
16.02	31			15.95	31		
16.02	32			15.95	32		
16.02	33			15.95	33		
16.02	34			15.95	34		
16.02	35			15.95	35		
16.02	36			15.95	36		
16.02	37			15.95	37		
16.02	38			15.95	38		
16.02	39			15.95	39		
16.02	40			15.95	40		

Table B-2.--continued

33PVCSLUGIN		RAW DATA		33PVCSLUGOUT		RAW DATA	
HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)	HEAD (feet)	TIME (sec)
20.39	0	20.47	41	20.43	0	20.60	41
20.40	1	20.47	42	19.90	1	20.60	42
19.35	2	20.47	43	19.04	2	20.60	43
20.47	3	20.47	44	18.23	3	20.60	44
20.47	4	20.47	45	20.59	4	20.60	45
20.47	5	20.47	46	20.60	5	20.60	46
20.47	6	20.47	47	20.59	6	20.60	47
20.47	7	20.47	48	20.60	7	20.60	48
20.47	8	20.47	49	20.60	8	20.60	49
20.47	9	20.47	50	20.60	9	20.60	50
20.48	10	20.47	51	20.59	10	20.60	51
20.48	11	20.47	52	20.60	11	20.60	52
20.48	12	20.47	53	20.60	12	20.60	53
20.48	13	20.46	54	20.60	13	20.60	54
20.49	14	20.46	55	20.59	14	20.60	55
20.49	15	20.46	56	20.59	15	20.60	56
20.49	16	20.46	57	20.59	16	20.60	57
20.49	17	20.46	58	20.59	17	20.60	58
20.49	18	20.46	59	20.59	18	20.60	59
20.49	19	20.46	60	20.59	19	20.60	60
20.49	20	20.46	61	20.59	20	20.60	80
20.49	21	20.45	62	20.59	21	20.60	100
20.49	22	20.45	63	20.59	22	20.60	120
20.49	23	20.45	64	20.59	23	20.61	140
20.48	24	20.45	65	20.59	23	20.61	160
20.48	25	20.45	66	20.59	25	20.61	180
20.48	26	20.45	67	20.59	26	20.61	200
20.48	27	20.45	68	20.59	27	20.61	220
20.48	28	20.45	69	20.59	28	20.62	240
20.48	29	20.44	70	20.60	29	20.62	260
20.48	30	20.44	71	20.60	30	20.62	280
20.48	31	20.44	72	20.60	31	20.62	300
20.48	32	20.44	73	20.59	32	20.62	330
20.48	33	20.44	74	20.60	33	20.62	360
20.48	34	20.44	75	20.59	34		
20.48	35			20.60	35		
20.48	36			20.60	36		
20.47	37			20.59	37		
20.47	38			20.60	38		
20.47	39			20.60	39		
20.47	40			20.60	40		

APPENDIX C
ACSWL PUMP SLUG TESTS RAW DATA AND CALCULATIONS

Table C-1. Pump Slug Test Calculations

GAS VENT # 8: 8PUMPSLUG1 & 8PUMPSLUG2 ANALYSIS

Bouwer and Rice Method (1976)

GAS VENT DESCRIPTION					
2rc =	0.50	ft	Le =	35.00	ft
2rw =	2.00	ft	Lw =	17.56	ft
h =	2.00	ft	DTW =	20.64	ft
L =	40.20	ft	H =	17.56	ft
well elevation (msl)				103.18	ft
landfill bottom elevation (msl)				65.08	ft
porosity of gravel pack, n				0.30	
Well Type: Fully Penetrating					

CALCULATIONS

Adjustment for rc due to gravel envelope:

Adjusted rc 0.586 ft

Bouwer and Rice Analog (Bouwer and Rice, 1976)

	Partially Penetrating		
where	A = N/A	therefore	
Le/rw = 35	B = N/A	ln(Re/rw) =	2.24
	Fully Penetrating		
	C = 2.2	Re =	9.39 ft

LINEAR REGRESSION

EARLY TIME FROM 0.0 TO 2.0 MINUTES (8SLUG1)
AND 0.0 TO 2.0 MINUTES (8SLUG2)

8SLUG1 Regression Output:		8SLUG2 Regression Output:	
Constant	1.134	Constant	1.146
Std Err of Y Est	0.0016	Std Err of Y Est	0.0012
R Squared	0.976	R Squared	0.985
No. of Observations	129	No. of Observations	129
Degrees of Freedom	127	Degrees of Freedom	127
X Coefficient(s)	-0.018	X Coefficient(s)	-0.017
Std Err of Coef.	0.0002	Std Err of Coef.	0.0002

Table C-1.--continued

GAS VENT # 8: ANALYSIS, cont.'
EARLY TIME LINEAR REGRESSION, continued

Selected Points for slope calculation:

t (min)	y (ft)	t (min)	y (ft)
0	13.62	0	14.01
1	13.08	1	13.48

Calculation Hydraulic Conductivity:

K =	4.427E-04 ft/min	K =	4.206E-04 ft/min
K =	2.249E-04 cm/sec	K =	2.137E-04 cm/sec

Volume of recharge FROM 0.0 TO 2.0 MINUTES (8SLUG1)
AND 0.0 TO 2.0 MINUTES (8SLUG2)

	8SLUG1	8SLUG2
	1.09 ft	1.09 ft
	1.17 ft^3	1.17 ft^3
	8.76 gal	8.76 gal
Rate of Recharge		
	4.38 gpm	4.38 gpm

LINEAR REGRESSION

LATE TIME FROM 2.0 TO 9.5 MINUTES (8SLUG1)
AND 2.0 TO 13.0 MINUTES (8SLUG2)

8SLUG1		8SLUG2	
Regression Output:		Regression Output:	
Constant	1.117	Constant	1.121
Std Err of Y Est	0.0010	Std Err of Y Est	0.0020
R Squared	0.992	R Squared	0.986
No. of Observations	156	No. of Observations	171
Degrees of Freedom	154	Degrees of Freedom	169
X Coefficient(s)	-0.008	X Coefficient(s)	-0.005
Std Err of Coef.	0.0000	Std Err of Coef.	0.0000

Selected Points for slope calculation:

t (min)	y (ft)	t (min)	y (ft)
0	13.08	0	13.21
1	12.83	1	13.05

Table C-1.--continued

GAS VENT # 8: ANALYSIS, cont.'
LATE TIME REGRESSION, continued

Calculation of Hydraulic Conductivity:

K =	2.142E-04	ft/min	K =	1.327E-04	ft/min
K =	1.088E-04	cm/sec	K =	6.741E-05	cm/sec

Volume of recharge FROM 2.0 TO 9.5 MINUTES (8SLUG1) AND 2.0 TO 13.0 MINUTES (8SLUG2)

8SLUG1			8SLUG2		
	2.81	ft		2.81	ft
	3.03	ft^3		3.03	ft^3
	22.68	gal		22.68	gal
Rate of Recharge					
	3.02	gpm		2.06	gpm

VOLUME PUMPED to water wagon

8SLUG1			8SLUG2		
Final weight	33640	lb	Final weight	34860	lb
Initial weight	32500	lb	Initial weight	33900	lb
Weight pumped	1140	lb	Weight pumped	960	lb
Volume pumped	136.9	gal	Volume pumped	115.3	gal
Volume Pumped:	18.3	ft^3	Volume Pumped:	15.4	ft^3
Static head	17.56	ft	Begin head	14.39	ft
Pumped head	3.80	ft	Pumped head	3.44	ft
Head change	13.76	ft	Head change	10.95	ft
Effective Volume in Well (n=0.3):	14.86	ft^3	Effective Volume in Well (n=0.3):	11.83	ft^3

Table C-1.--continued

GAS VENT # 20: 20PUMPSLUG1 & 20PUMPSLUG2 ANALYSIS

Bouwer and Rice Method (1976)

GAS VENT DESCRIPTION					
2rc =	0.50	ft	Le =	20.00	ft
2rw =	2.00	ft	Lw =	15.11	ft
h =	2.78	ft	DTW =	19.62	ft
L =	37.50	ft	H =	20.81	ft
well elevation (msl)				110.42	ft
landfill bottom elevation (msl)				70.00	ft
porosity of gravel pack, n				0.30	
Well Type: Partially Penetrating					

CALCULATIONS

Adjustment for rc due to gravel envelope:

Adjusted rc 0.586 ft

Bouwer and Rice Analog		(Bouwer and Rice, 1976)				
		Partially Penetrating				
where		A =	2.1	therefore		
Le/rw =	20	B =	0.3	ln(Re/rw) =	1.86	
		Fully Penetrating				
		C =	N/A	Re =	6.46	ft

LINEAR REGRESSION

EARLY TIME FROM 0.0 TO 0.40 MINUTES (20SLUG1) AND 0.0 TO 0.30 MINUTES (20SLUG2)

20SLUG2		20SLUG1	
Regression Output:		Regression Output:	
Constant	1.028	Constant	1.003
Std Err of Y Est	0.0032	Std Err of Y Est	0.0088
R Squared	0.990	R Squared	0.691
No. of Observations	20	No. of Observations	26
Degrees of Freedom	18	Degrees of Freedom	24
X Coefficient(s)	-0.327	X Coefficient(s)	-0.036
Std Err of Coef.	0.008	Std Err of Coef.	0.015

Table C-1.--continued

GAS VENT # 20: ANALYSIS, cont.'
EARLY TIME LINEAR REGRESSION, continued

Selected Points for slope calculation:

t (min)	y (ft)	t (min)	y (ft)
0	10.66	0	10.07
1	5.03	1	4.43

Calculation Hydraulic Conductivity:

K =	1.183E-02	ft/min	K =	1.294E-02	ft/min
K =	6.012E-03	cm/sec	K =	6.572E-03	cm/sec

Volume of recharge FROM 0.0 TO 0.40 MINUTES (20SLUG1) AND 0.0 TO 0.30 MINUTES (20SLUG2)

	20SLUG1		20SLUG2	
	2.62	ft	2.81	ft
	0.52	ft^3	0.55	ft^3
	3.85	gal	4.12	gal
Rate of Recharge				
	9.64	gpm	13.73	gpm

LINEAR REGRESSION continued

LATE TIME FROM 0.8 TO 2.9 MINUTES (20SLUG1) AND 0.5 TO 2.2 MINUTES (20SLUG2)

20SLUG1 Regression Output:		20SLUG2 Regression Output:	
Constant	0.869	Constant	0.886
Std Err of Y Est	0.0021	Std Err of Y Est	0.0026
R Squared	0.994	R Squared	0.991
No. of Observations	136	No. of Observations	110
Degrees of Freedom	134	Degrees of Freedom	108
X Coefficient(s)	-0.044	X Coefficient(s)	-0.053
Std Err of Coef.	0.0002	Std Err of Coef.	0.0010

Selected Points for slope calculation:

t (min)	y (ft)	t (min)	y (ft)
0	7.40	0	7.69
1	6.68	1	6.80

Table C-1.--continued

GAS VENT # 20: ANALYSIS, cont.'
LATE TIME REGRESSION, continued

Calculation of Hydraulic Conductivity:

K =	1.613E-03	ft/min	K =	1.938E-03	ft/min
K =	8.194E-04	cm/sec	K =	9.845E-04	cm/sec

Volume of recharge FROM 0.8 TO 2.9 MINUTES (20SLUG1) AND 0.5 TO 2.2 MINUTES (20SLUG2)

	20SLUG1		20SLUG2	
	1.45	ft	1.45	ft
	1.56	ft^3	1.56	ft^3
	11.70	gal	11.70	gal
Rate of Recharge				
	5.57	gpm	6.88	gpm

Table C-1.--continued

GAS VENT #20: ANALYSIS, cont.'
TOTAL VOLUME PUMPED from water wagon

20SLUG1			20SLUG2		
Final weight	31700	lb	Final weight	32500	lb
Initial weight	30940	lb	Initial weight	31700	lb
Weight pumped	760	lb	Weight pumped	800	lb
Volume pumped	91.3	gal	Volume pumped	96.1	gal
Volume Pumped:	12.2	ft^3	Volume Pumped:	12.8	ft^3
Static head	15.11	ft	Begin head	12.40	ft
Pumped head	4.53	ft	Pumped head	4.53	ft
Head change	10.58	ft	Head change	7.87	ft
Effective Volume in			Effective Volume in		
Well (assuming n = 0.3)	11.41	ft^3	Well (assuming n=0.	8.49	ft^3

Table C-1.--continued

GAS VENT # 33: 33PUMPSLUG1 & 33PUMPSLUG2 ANALYSIS

Bouwer and Rice Method (1976)

GAS VENT DESCRIPTION					
2rc =	0.50	ft	Le =	35.00	ft
2rw =	2.00	ft	Lw =	20.45	ft
h =	2.94	ft	DTW =	27.96	ft
L =	51.35	ft	H =	26.26	ft
well elevation (msl)				124.07	ft
landfill bottom elevation (msl)				70.00	ft
porosity of gravel pack, n				0.30	
Well Type: Partially Penetrating					

CALCULATIONS

Adjustment for rc due to gravel envelope:

Adjusted rc 0.586 ft

Bouwer and Rice Analog (Bouwer and Rice, 1976)

		Partially Penetrating			
where		A = 2.6	therefore		
Le/rw =	35	B = 0.4	ln(Re/rw) =	2.18	
		Fully Penetrating			
		C = N/A	Re =	8.84	ft

LINEAR REGRESSION

LATE TIME FROM 0.0 TO 10.0 MINUTES (33SLUG1) AND 0.0 TO 6.0 MINUTES (33SLUG2)

33S		33SLUG1	
Regression Outpu		Regression Output:	
Constant	1.190	Constant	1.173
Std Err of Y Est	0.0048	Std Err of Y Est	0.0089
R Squared	0.996	R Squared	0.988
No. of Observations	45	No. of Observations	27
Degrees of Freedom	43	Degrees of Freedom	25
X Coefficient(s)	-0.027	X Coefficient(s)	-0.044
Std Err of Coef.	0.000	Std Err of Coef.	0.001

Table C-1.--continued

GAS VENT # 33: ANALYSIS, cont.'
LATE TIME LINEAR REGRESSION, continued

Selected Points for slope calculation:

t (min)	y (ft)	t (min)	y (ft)
0	15.48	0	14.91
1.1	14.43	1.1	13.29

Calculation Hydraulic Conductivity:

K =	6.833E-04	ft/min	K =	1.190E-03	ft/min
K =	3.478E-04	cm/sec	K =	5.685E-04	cm/sec

Effective Volume of recharge FROM 0.0 TO 10.0 MINUTES (33SLUG1)
AND 0.0 TO 6.0 MINUTES (33SLUG2)

	33SLUG2		33SLUG1	
	7.51	ft	7.33	ft
	8.10	ft^3	7.91	ft^3
	60.60	gal	59.15	gal
Rate of Recharge				
	6.06	gpm	9.86	gpm

Table C-1.--continued

GAS VENT # 33: ANALYSIS, cont.'
TOTAL VOLUME PUMPED from water wagon

33SLUG1			33SLUG2		
Final weight	33380	lb	Final weight	34480	lb
Initial weight	31840	lb	Initial weight	33380	lb
Weight pumped	1540	lb	Weight pumped	1100	lb
Volume pumped	184.9	gal	Volume pumped	132.1	gal
Volume Pumped:	24.7	ft^3	Volume Pumped:	17.7	ft^3
Static head	20.45	ft	Begin head	15.56	ft
Pumped head	4.43	ft	Pumped head	4.43	ft
Head change	16.02	ft	Head change	11.13	ft
Effective Volume in Well (n = 0.3):	17.30	ft^3	Effective Volume in Well (n=0.3):	12.02	ft^3

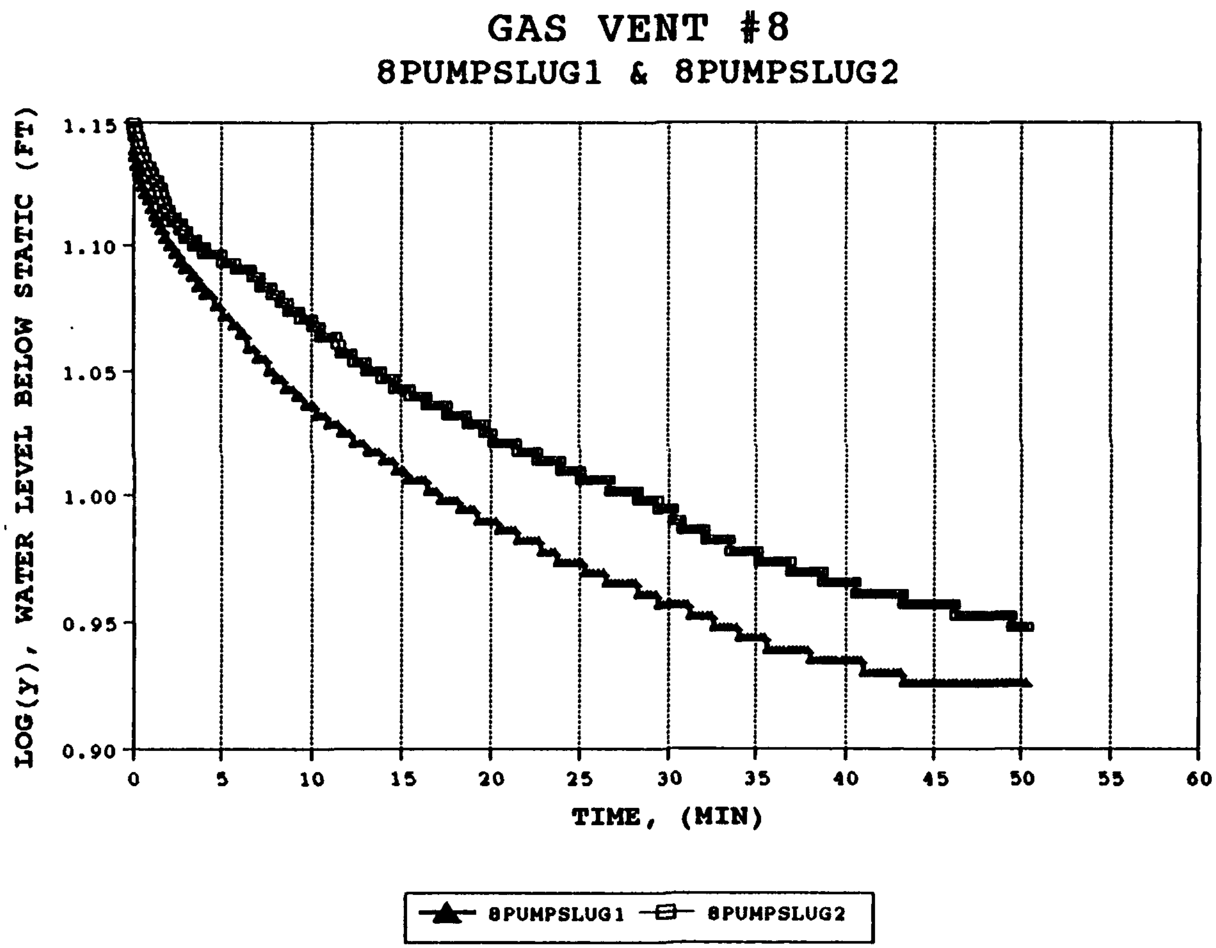


Figure C-1. Pump Slug Test Semilog Plots

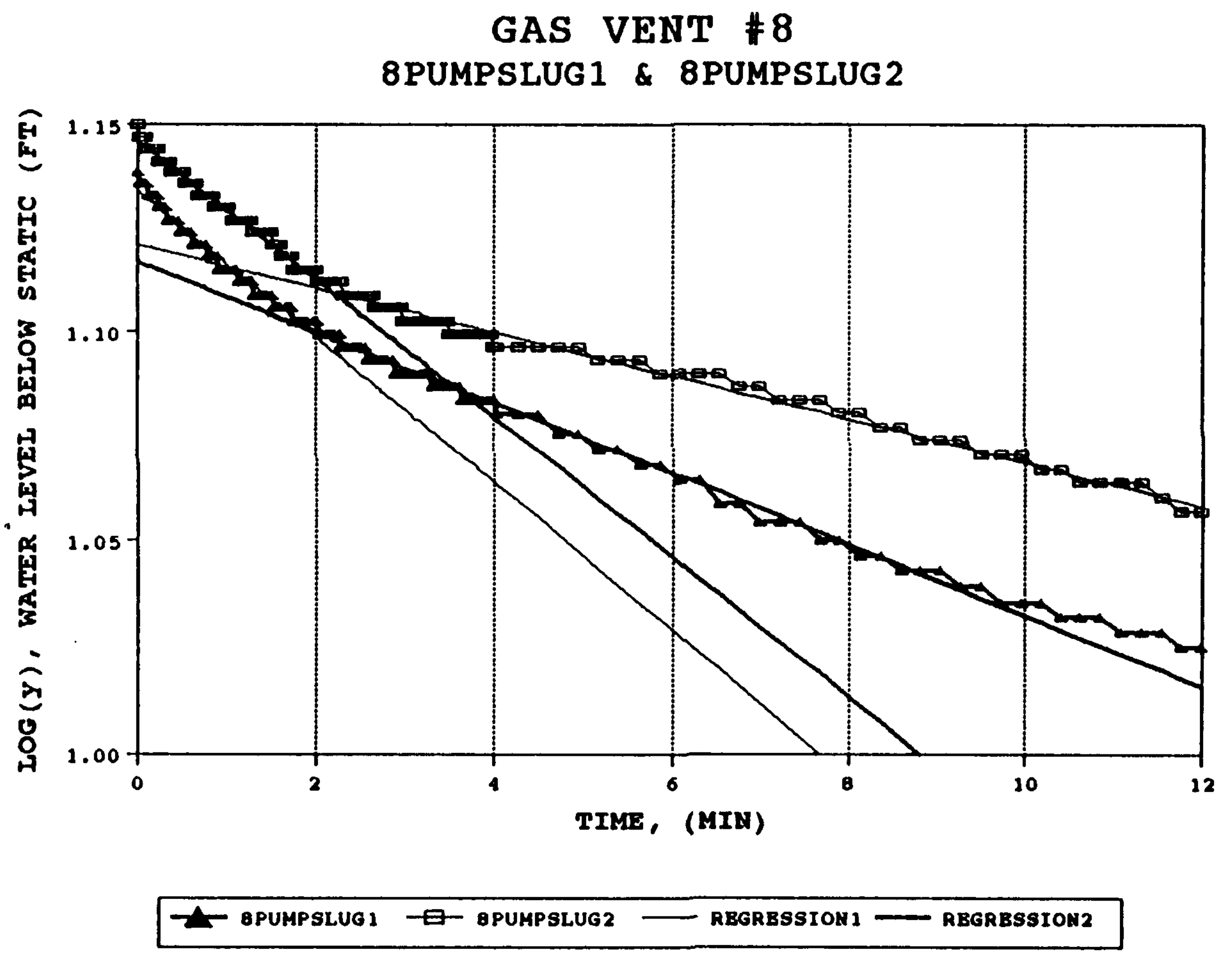


Figure C-1. Pump Slug Test Semilog Plots

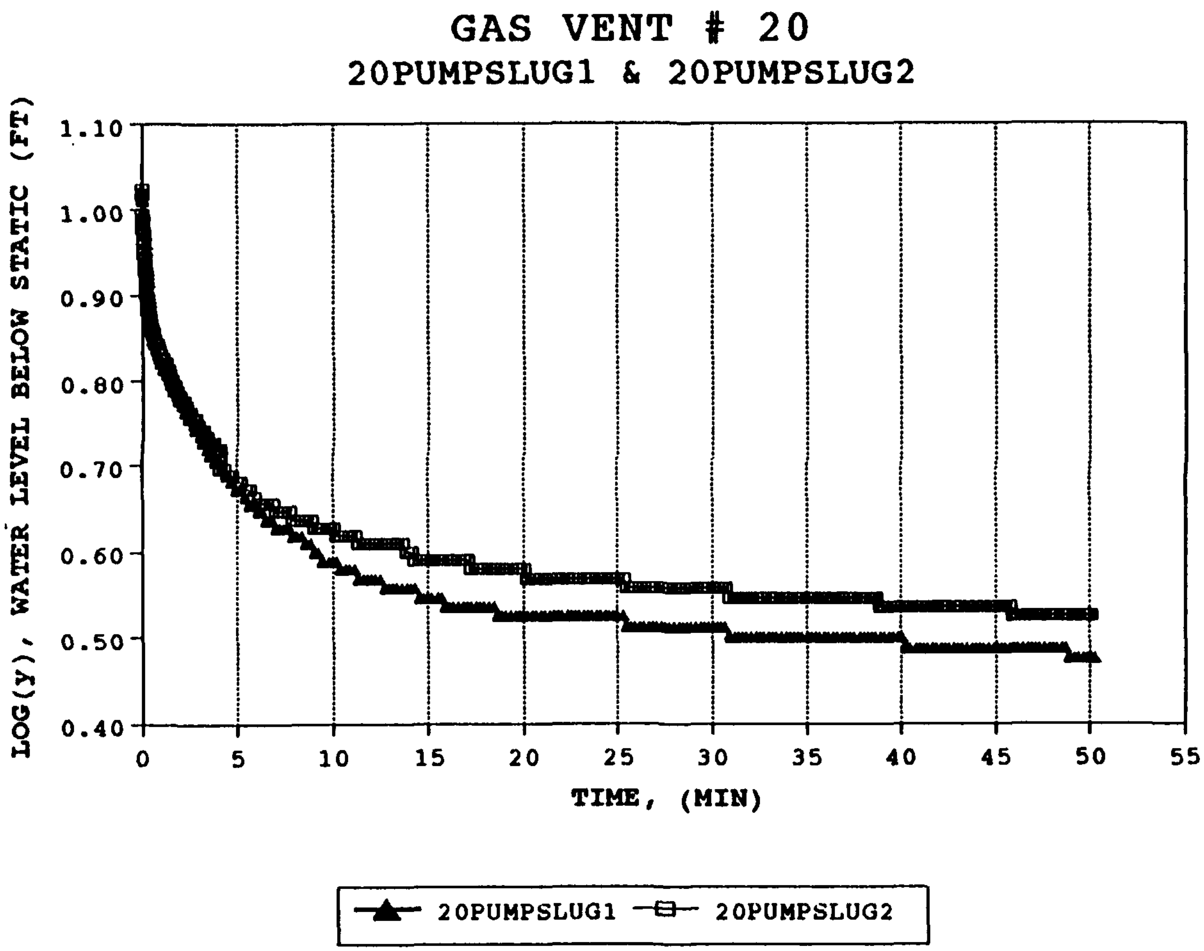


Figure C-1.--continued

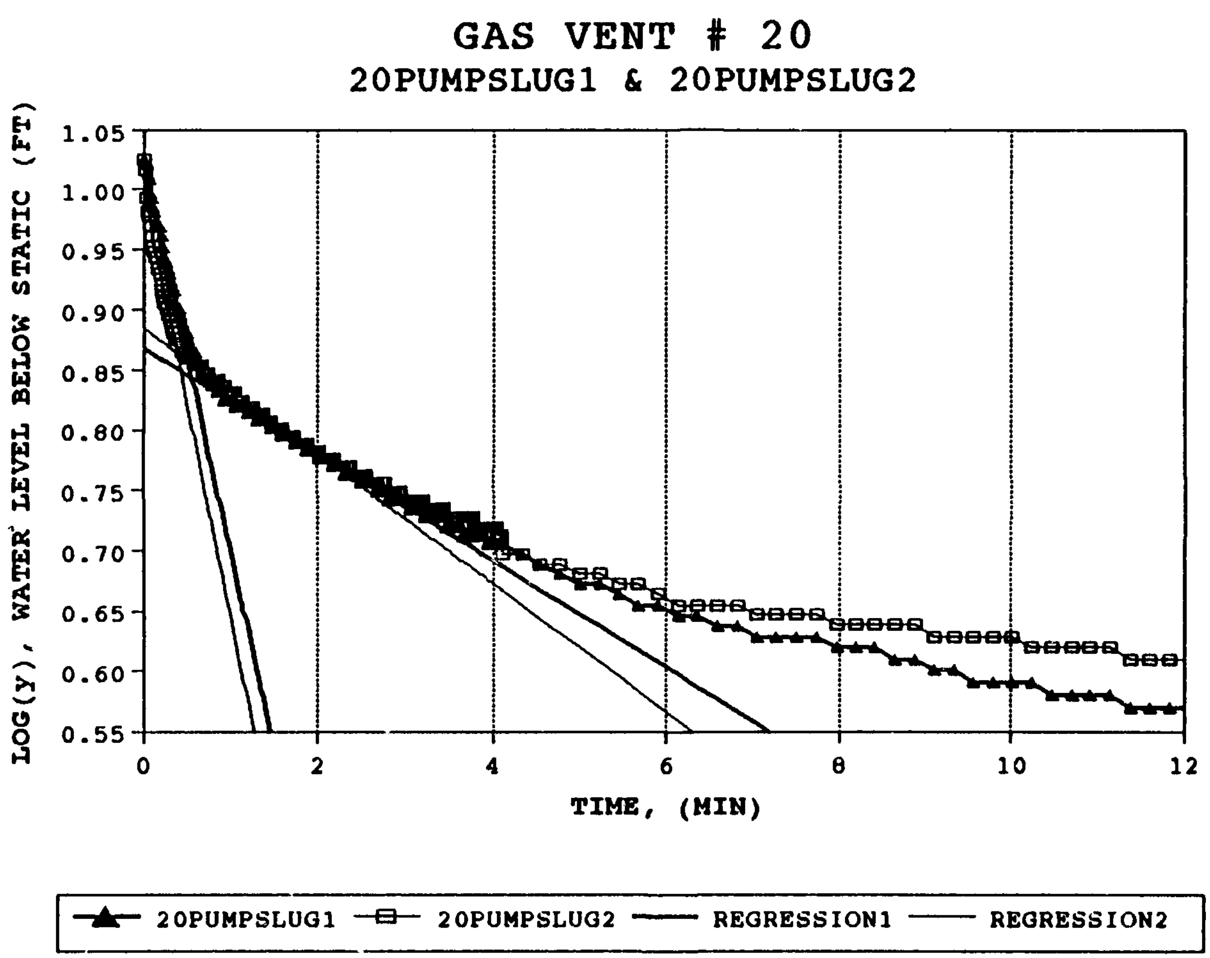


Figure C-1.--continued

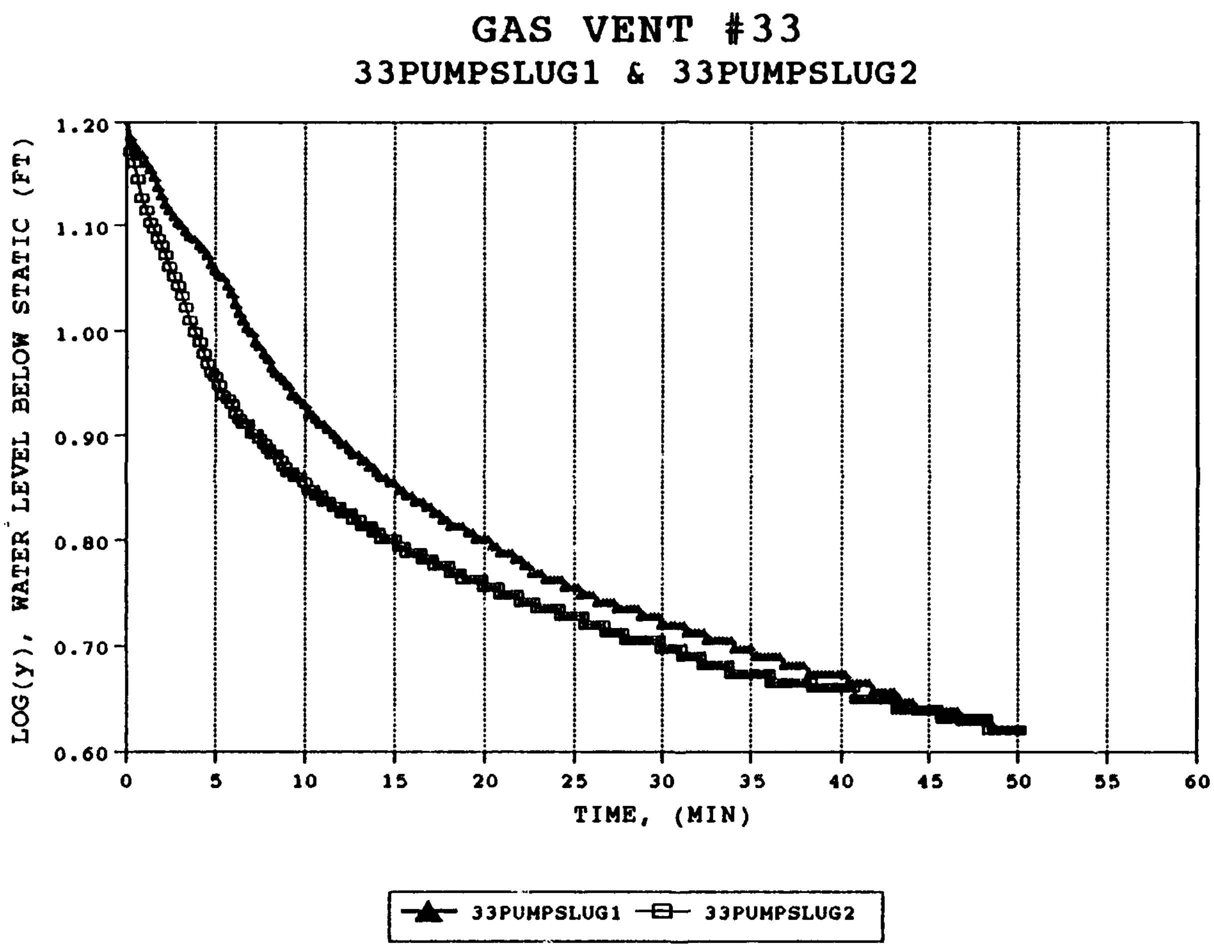


Figure C-1.--continued

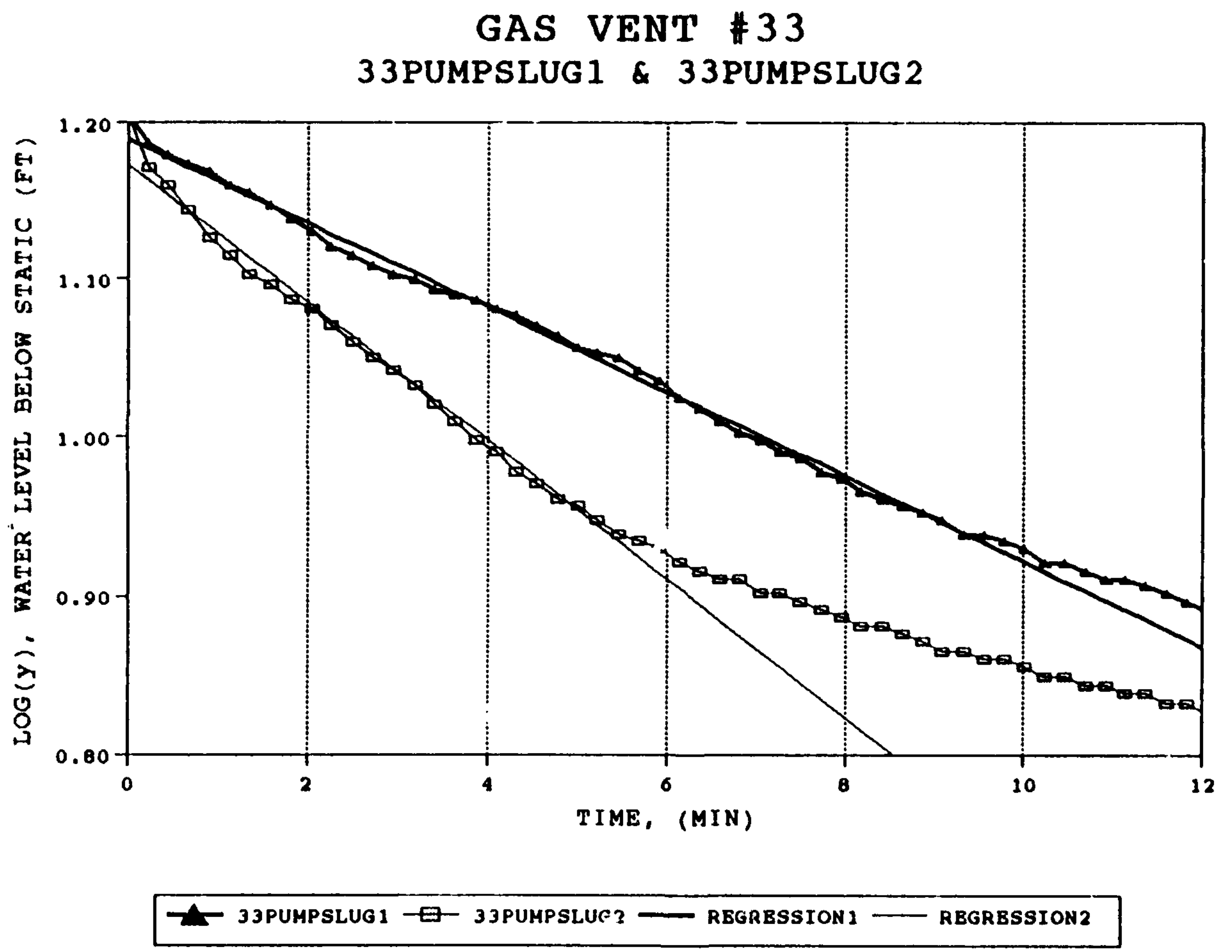


Figure C-1.--continued

Table C-2. Pump Slug Test Raw Data

RAW DATA-GAS VENT 8				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
0.000	3.062	13.756	3.141	14.118
0.228	3.023	13.575	3.102	13.937
0.455	2.984	13.394	3.062	13.756
0.683	2.945	13.213	3.023	13.575
0.910	2.905	13.032	3.003	13.485
1.138	2.886	12.942	2.984	13.394
1.365	2.866	12.851	2.964	13.304
1.592	2.846	12.761	2.945	13.213
1.820	2.827	12.670	2.905	13.032
2.048	2.807	12.580	2.886	12.942
2.275	2.788	12.489	2.886	12.942
2.503	2.788	12.489	2.866	12.851
2.730	2.768	12.399	2.846	12.761
2.958	2.748	12.308	2.846	12.761
3.185	2.748	12.308	2.827	12.670
3.413	2.729	12.218	2.827	12.670
3.640	2.709	12.127	2.807	12.580
3.868	2.709	12.127	2.807	12.580
4.095	2.688	12.030	2.788	12.489
4.323	2.688	12.030	2.788	12.489
4.550	2.660	11.900	2.788	12.489
4.778	2.660	11.900	2.788	12.489
5.005	2.638	11.800	2.768	12.399
5.232	2.638	11.800	2.768	12.399
5.460	2.616	11.700	2.768	12.399
5.687	2.616	11.700	2.748	12.308
5.915	2.611	11.675	2.748	12.308
6.142	2.611	11.675	2.748	12.308
6.370	2.573	11.500	2.748	12.308
6.597	2.573	11.500	2.729	12.218
6.825	2.530	11.300	2.729	12.218
7.052	2.530	11.300	2.709	12.127
7.280	2.530	11.300	2.709	12.127
7.507	2.513	11.222	2.709	12.127
7.735	2.513	11.222	2.689	12.037
7.962	2.493	11.132	2.689	12.037
8.190	2.493	11.132	2.670	11.946

Table C-2.--continued

RAW DATA-GAS VENT 8 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
8.417	2.473	11.041	2.670	11.946
8.645	2.473	11.041	2.650	11.856
8.872	2.473	11.041	2.650	11.856
9.100	2.454	10.951	2.650	11.856
9.327	2.454	10.951	2.631	11.765
9.555	2.434	10.860	2.631	11.765
9.782	2.434	10.860	2.631	11.765
10.010	2.434	10.860	2.611	11.675
10.237	2.415	10.770	2.611	11.675
10.465	2.415	10.770	2.591	11.584
10.692	2.415	10.770	2.591	11.584
10.920	2.395	10.679	2.591	11.584
11.147	2.395	10.679	2.591	11.584
11.375	2.395	10.679	2.572	11.494
11.602	2.375	10.589	2.552	11.403
11.830	2.375	10.589	2.552	11.403
12.057	2.375	10.589	2.552	11.403
12.285	2.356	10.498	2.532	11.313
12.512	2.356	10.498	2.532	11.313
12.740	2.356	10.498	2.532	11.313
12.967	2.336	10.408	2.513	11.222
13.195	2.336	10.408	2.513	11.222
13.422	2.336	10.408	2.513	11.222
13.650	2.336	10.408	2.513	11.222
13.877	2.316	10.317	2.493	11.132
14.105	2.316	10.317	2.493	11.132
14.332	2.316	10.317	2.493	11.132
14.560	2.297	10.227	2.473	11.041
14.787	2.297	10.227	2.473	11.041
15.015	2.297	10.227	2.473	11.041
15.242	2.277	10.136	2.473	11.041
15.470	2.277	10.136	2.454	10.951
15.697	2.277	10.136	2.454	10.951
15.925	2.277	10.136	2.454	10.951
16.152	2.277	10.136	2.454	10.951
16.380	2.258	10.046	2.434	10.860
16.607	2.258	10.046	2.434	10.860

Table C-2.--continued

RAW DATA-GAS VENT 8 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
16.835	2.258	10.046	2.434	10.860
17.062	2.238	9.955	2.434	10.860
17.290	2.238	9.955	2.434	10.860
17.517	2.238	9.955	2.415	10.770
17.745	2.238	9.955	2.415	10.770
17.972	2.238	9.955	2.415	10.770
18.200	2.218	9.865	2.415	10.770
18.427	2.218	9.865	2.415	10.770
18.655	2.218	9.865	2.395	10.679
18.882	2.218	9.865	2.395	10.679
19.110	2.199	9.774	2.395	10.679
19.337	2.199	9.774	2.395	10.679
19.565	2.199	9.774	2.375	10.589
19.793	2.199	9.774	2.375	10.589
20.020	2.199	9.774	2.356	10.498
20.248	2.179	9.684	2.356	10.498
20.475	2.179	9.684	2.356	10.498
20.703	2.179	9.684	2.356	10.498
20.930	2.179	9.684	2.356	10.498
21.158	2.179	9.684	2.356	10.498
21.385	2.159	9.593	2.336	10.408
21.613	2.159	9.593	2.336	10.408
21.840	2.159	9.593	2.336	10.408
22.068	2.159	9.593	2.336	10.408
22.295	2.159	9.593	2.336	10.408
22.523	2.159	9.593	2.316	10.317
22.750	2.140	9.503	2.316	10.317
22.978	2.140	9.503	2.316	10.317
23.205	2.140	9.503	2.316	10.317
23.433	2.140	9.503	2.316	10.317
23.660	2.120	9.412	2.316	10.317
23.888	2.120	9.412	2.297	10.227
24.115	2.120	9.412	2.297	10.227
24.343	2.120	9.412	2.297	10.227
24.570	2.120	9.412	2.297	10.227
24.798	2.120	9.412	2.297	10.227
25.025	2.120	9.412	2.277	10.136

Table C-2.--continued

RAW DATA-GAS VENT 8 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
25.253	2.100	9.322	2.277	10.136
25.480	2.100	9.322	2.277	10.136
25.708	2.100	9.322	2.277	10.136
25.935	2.100	9.322	2.277	10.136
26.163	2.100	9.322	2.277	10.136
26.390	2.081	9.231	2.277	10.136
26.618	2.081	9.231	2.258	10.046
26.845	2.081	9.231	2.258	10.046
27.073	2.081	9.231	2.258	10.046
27.300	2.081	9.231	2.258	10.046
27.528	2.081	9.231	2.258	10.046
27.755	2.081	9.231	2.258	10.046
27.983	2.081	9.231	2.258	10.046
28.210	2.061	9.141	2.238	9.955
28.438	2.061	9.141	2.238	9.955
28.665	2.061	9.141	2.238	9.955
28.893	2.061	9.141	2.238	9.955
29.120	2.061	9.141	2.238	9.955
29.348	2.042	9.050	2.218	9.865
29.575	2.042	9.050	2.218	9.865
29.803	2.042	9.050	2.218	9.865
30.030	2.042	9.050	2.218	9.865
30.258	2.042	9.050	2.199	9.774
30.485	2.042	9.050	2.199	9.774
30.713	2.042	9.050	2.179	9.684
30.940	2.042	9.050	2.179	9.684
31.168	2.022	8.960	2.179	9.684
31.395	2.022	8.960	2.179	9.684
31.623	2.022	8.960	2.179	9.684
31.850	2.022	8.960	2.179	9.684
32.078	2.022	8.960	2.159	9.593
32.305	2.022	8.960	2.159	9.593
32.533	2.002	8.869	2.159	9.593
32.760	2.002	8.869	2.159	9.593
32.988	2.002	8.869	2.159	9.593
33.215	2.002	8.869	2.159	9.593

Table C-2.--continued

RAW DATA-GAS VENT 8 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
33.443	2.002	8.869	2.140	9.503
33.670	2.002	8.869	2.140	9.503
33.898	1.983	8.779	2.140	9.503
34.125	1.983	8.779	2.140	9.503
34.353	1.983	8.779	2.140	9.503
34.580	1.983	8.779	2.140	9.503
34.808	1.983	8.779	2.140	9.503
35.035	1.983	8.779	2.140	9.503
35.263	1.983	8.779	2.120	9.412
35.490	1.963	8.688	2.120	9.412
35.718	1.963	8.688	2.120	9.412
35.945	1.963	8.688	2.120	9.412
36.173	1.963	8.688	2.120	9.412
36.400	1.963	8.688	2.120	9.412
36.628	1.963	8.688	2.120	9.412
36.855	1.963	8.688	2.100	9.322
37.083	1.963	8.688	2.100	9.322
37.310	1.963	8.688	2.100	9.322
37.538	1.963	8.688	2.100	9.322
37.765	1.963	8.688	2.100	9.322
37.993	1.943	8.598	2.100	9.322
38.220	1.943	8.598	2.100	9.322
38.448	1.943	8.598	2.100	9.322
38.675	1.943	8.598	2.081	9.231
38.903	1.943	8.598	2.081	9.231
39.130	1.943	8.598	2.081	9.231
39.358	1.943	8.598	2.081	9.231
39.585	1.943	8.598	2.081	9.231
39.813	1.943	8.598	2.081	9.231
40.040	1.943	8.598	2.081	9.231
40.268	1.943	8.598	2.081	9.231
40.495	1.943	8.598	2.061	9.141
40.723	1.943	8.598	2.061	9.141
40.950	1.924	8.507	2.061	9.141
41.178	1.924	8.507	2.061	9.141
41.405	1.924	8.507	2.061	9.141
41.633	1.924	8.507	2.061	9.141

Table C-2.--continued

RAW DATA-GAS VENT 8 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
41.860	1.924	8.507	2.061	9.141
42.088	1.924	8.507	2.061	9.141
42.315	1.924	8.507	2.061	9.141
42.543	1.924	8.507	2.061	9.141
42.770	1.924	8.507	2.061	9.141
42.998	1.924	8.507	2.061	9.141
43.225	1.904	8.417	2.042	9.050
43.453	1.904	8.417	2.042	9.050
43.680	1.904	8.417	2.042	9.050
43.908	1.904	8.417	2.042	9.050
44.135	1.904	8.417	2.042	9.050
44.363	1.904	8.417	2.042	9.050
44.590	1.904	8.417	2.042	9.050
44.818	1.904	8.417	2.042	9.050
45.045	1.904	8.417	2.042	9.050
45.273	1.904	8.417	2.042	9.050
45.500	1.904	8.417	2.042	9.050
45.728	1.904	8.417	2.042	9.050
45.955	1.904	8.417	2.042	9.050
46.183	1.904	8.417	2.022	8.960
46.410	1.904	8.417	2.022	8.960
46.638	1.904	8.417	2.022	8.960
46.865	1.904	8.417	2.022	8.960
47.093	1.904	8.417	2.022	8.960
47.320	1.904	8.417	2.022	8.960
47.548	1.904	8.417	2.022	8.960
47.775	1.904	8.417	2.022	8.960
48.003	1.904	8.417	2.022	8.960
48.230	1.904	8.417	2.022	8.960
48.458	1.904	8.417	2.022	8.960
48.685	1.904	8.417	2.022	8.960
48.913	1.904	8.417	2.022	8.960
49.140	1.904	8.417	2.022	8.960
49.368	1.904	8.417	2.002	8.869
49.595	1.904	8.417	2.002	8.869
49.823	1.904	8.417	2.002	8.869
50.050	1.904	8.417	2.002	8.869

Table C-2.--continued

RAW DATA-GAS VENT 20				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
0.000	2.375	10.589	2.376	10.590
0.228	2.022	8.960	1.865	8.237
0.455	1.767	7.784	1.669	7.332
0.683	1.610	7.060	1.610	7.060
0.910	1.551	6.788	1.571	6.879
1.138	1.512	6.607	1.531	6.698
1.365	1.472	6.426	1.492	6.517
1.592	1.433	6.245	1.433	6.246
1.820	1.413	6.155	1.414	6.155
2.048	1.374	5.974	1.374	5.974
2.275	1.355	5.883	1.355	5.884
2.503	1.315	5.702	1.335	5.793
2.730	1.296	5.611	1.315	5.703
2.958	1.276	5.521	1.276	5.522
3.185	1.256	5.430	1.276	5.522
3.413	1.237	5.340	1.257	5.431
3.640	1.217	5.249	1.237	5.341
3.868	1.198	5.159	1.217	5.250
4.095	1.178	5.068	1.178	5.069
4.328	1.158	4.978	1.158	4.979
4.555	1.139	4.887	1.139	4.888
4.782	1.119	4.797	1.139	4.888
5.010	1.099	4.706	1.119	4.798
5.237	1.099	4.706	1.119	4.798
5.465	1.080	4.616	1.100	4.707
5.692	1.060	4.525	1.100	4.707
5.920	1.060	4.525	1.080	4.617
6.147	1.040	4.435	1.060	4.526
6.375	1.040	4.435	1.060	4.526
6.602	1.021	4.344	1.060	4.526
6.830	1.021	4.344	1.060	4.526
7.057	1.001	4.254	1.041	4.436
7.285	1.001	4.254	1.041	4.436
7.512	1.001	4.254	1.041	4.436
7.740	1.001	4.254	1.041	4.436
7.967	0.982	4.163	1.021	4.345
8.195	0.982	4.163	1.021	4.345

Table C-2.--continued

RAW DATA-GAS VENT 20 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
8.422	0.982	4.163	1.021	4.345
8.650	0.962	4.073	1.021	4.345
8.877	0.962	4.073	1.021	4.345
9.105	0.942	3.982	1.001	4.255
9.332	0.942	3.982	1.001	4.255
9.560	0.923	3.892	1.001	4.255
9.787	0.923	3.892	1.001	4.255
10.015	0.923	3.892	1.001	4.255
10.242	0.923	3.892	0.982	4.164
10.470	0.903	3.801	0.982	4.164
10.697	0.903	3.801	0.982	4.164
10.925	0.903	3.801	0.982	4.164
11.152	0.903	3.801	0.982	4.164
11.380	0.883	3.711	0.962	4.074
11.607	0.883	3.711	0.962	4.074
11.835	0.883	3.711	0.962	4.074
12.062	0.883	3.711	0.962	4.074
12.290	0.883	3.711	0.962	4.074
12.517	0.883	3.711	0.962	4.074
12.745	0.864	3.620	0.962	4.074
12.972	0.864	3.620	0.962	4.074
13.200	0.864	3.620	0.962	4.074
13.427	0.864	3.620	0.962	4.074
13.655	0.864	3.620	0.962	4.074
13.882	0.864	3.620	0.942	3.983
14.110	0.864	3.620	0.942	3.983
14.337	0.864	3.620	0.923	3.893
14.565	0.844	3.530	0.923	3.893
14.792	0.844	3.530	0.923	3.893
15.020	0.844	3.530	0.923	3.893
15.247	0.844	3.530	0.923	3.893
15.475	0.844	3.530	0.923	3.893
15.702	0.844	3.530	0.923	3.893
15.930	0.824	3.439	0.923	3.893
16.157	0.824	3.439	0.923	3.893
16.385	0.824	3.439	0.923	3.893
16.612	0.824	3.439	0.923	3.893

Table C-2.--continued

RAW DATA-GAS VENT 20 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
16.840	0.824	3.439	0.923	3.893
17.067	0.824	3.439	0.923	3.893
17.295	0.824	3.439	0.903	3.802
17.522	0.824	3.439	0.903	3.802
17.750	0.824	3.439	0.903	3.802
17.977	0.824	3.439	0.903	3.802
18.205	0.824	3.439	0.903	3.802
18.432	0.824	3.439	0.903	3.802
18.660	0.805	3.349	0.903	3.802
18.887	0.805	3.349	0.903	3.802
19.115	0.805	3.349	0.903	3.802
19.342	0.805	3.349	0.903	3.802
19.570	0.805	3.349	0.903	3.802
19.798	0.805	3.349	0.903	3.802
20.025	0.805	3.349	0.903	3.802
20.253	0.805	3.349	0.884	3.712
20.480	0.805	3.349	0.884	3.712
20.708	0.805	3.349	0.884	3.712
20.935	0.805	3.349	0.884	3.712
21.163	0.805	3.349	0.884	3.712
21.390	0.805	3.349	0.884	3.712
21.618	0.805	3.349	0.884	3.712
21.845	0.805	3.349	0.884	3.712
22.073	0.805	3.349	0.884	3.712
22.300	0.805	3.349	0.884	3.712
22.528	0.805	3.349	0.884	3.712
22.755	0.805	3.349	0.884	3.712
22.983	0.805	3.349	0.884	3.712
23.210	0.805	3.349	0.884	3.712
23.438	0.805	3.349	0.884	3.712
23.665	0.805	3.349	0.884	3.712
23.893	0.805	3.349	0.884	3.712
24.120	0.805	3.349	0.884	3.712
24.348	0.805	3.349	0.884	3.712
24.575	0.805	3.349	0.884	3.712
24.803	0.805	3.349	0.884	3.712
25.030	0.805	3.349	0.884	3.712

Table C-2.--continued

RAW DATA-GAS VENT 20 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
25.258	0.805	3.349	0.884	3.712
25.485	0.785	3.258	0.864	3.621
25.713	0.785	3.258	0.864	3.621
25.940	0.785	3.258	0.864	3.621
26.168	0.785	3.258	0.864	3.621
26.395	0.785	3.258	0.864	3.621
26.623	0.785	3.258	0.864	3.621
26.850	0.785	3.258	0.864	3.621
27.078	0.785	3.258	0.864	3.621
27.305	0.785	3.258	0.864	3.621
27.533	0.785	3.258	0.864	3.621
27.760	0.785	3.258	0.864	3.621
27.988	0.785	3.258	0.864	3.621
28.215	0.785	3.258	0.864	3.621
28.443	0.785	3.258	0.864	3.621
28.670	0.785	3.258	0.864	3.621
28.898	0.785	3.258	0.864	3.621
29.125	0.785	3.258	0.864	3.621
29.353	0.785	3.258	0.864	3.621
29.580	0.785	3.258	0.864	3.621
29.808	0.785	3.258	0.864	3.621
30.035	0.785	3.258	0.864	3.621
30.263	0.785	3.258	0.864	3.621
30.490	0.785	3.258	0.864	3.621
30.718	0.785	3.258	0.864	3.621
30.945	0.766	3.168	0.844	3.531
31.173	0.766	3.168	0.844	3.531
31.400	0.766	3.168	0.844	3.531
31.628	0.766	3.168	0.844	3.531
31.855	0.766	3.168	0.844	3.531
32.083	0.766	3.168	0.844	3.531
32.310	0.766	3.168	0.844	3.531
32.538	0.766	3.168	0.844	3.531
32.765	0.766	3.168	0.844	3.531
32.993	0.766	3.168	0.844	3.531
33.220	0.766	3.168	0.844	3.531

Table C-2.--continued

RAW DATA-GAS VENT 20 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
33.448	0.766	3.168	0.844	3.531
33.675	0.766	3.168	0.844	3.531
33.903	0.766	3.168	0.844	3.531
34.130	0.766	3.168	0.844	3.531
34.358	0.766	3.168	0.844	3.531
34.585	0.766	3.168	0.844	3.531
34.813	0.766	3.168	0.844	3.531
35.040	0.766	3.168	0.844	3.531
35.268	0.766	3.168	0.844	3.531
35.495	0.766	3.168	0.844	3.531
35.723	0.766	3.168	0.844	3.531
35.950	0.766	3.168	0.844	3.531
36.178	0.766	3.168	0.844	3.531
36.405	0.766	3.168	0.844	3.531
36.633	0.766	3.168	0.844	3.531
36.860	0.766	3.168	0.844	3.531
37.088	0.766	3.168	0.844	3.531
37.315	0.766	3.168	0.844	3.531
37.543	0.766	3.168	0.844	3.531
37.770	0.766	3.168	0.844	3.531
37.998	0.766	3.168	0.844	3.531
38.225	0.766	3.168	0.844	3.531
38.453	0.766	3.168	0.844	3.531
38.680	0.766	3.168	0.844	3.531
38.908	0.766	3.168	0.825	3.440
39.135	0.766	3.168	0.825	3.440
39.363	0.766	3.168	0.825	3.440
39.590	0.766	3.168	0.825	3.440
39.818	0.766	3.168	0.825	3.440
40.045	0.766	3.168	0.825	3.440
40.273	0.746	3.077	0.825	3.440
40.500	0.746	3.077	0.825	3.440
40.728	0.746	3.077	0.825	3.440
40.955	0.746	3.077	0.825	3.440
41.183	0.746	3.077	0.825	3.440
41.410	0.746	3.077	0.825	3.440
41.638	0.746	3.077	0.825	3.440

Table C-2.--continued

RAW DATA-GAS VENT 20 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
41.865	0.746	3.077	0.825	3.440
42.093	0.746	3.077	0.825	3.440
42.320	0.746	3.077	0.825	3.440
42.548	0.746	3.077	0.825	3.440
42.775	0.746	3.077	0.825	3.440
43.003	0.746	3.077	0.825	3.440
43.230	0.746	3.077	0.825	3.440
43.458	0.746	3.077	0.825	3.440
43.685	0.746	3.077	0.825	3.440
43.913	0.746	3.077	0.825	3.440
44.140	0.746	3.077	0.825	3.440
44.368	0.746	3.077	0.825	3.440
44.595	0.746	3.077	0.825	3.440
44.823	0.746	3.077	0.825	3.440
45.050	0.746	3.077	0.825	3.440
45.278	0.746	3.077	0.825	3.440
45.505	0.746	3.077	0.825	3.440
45.733	0.746	3.077	0.825	3.440
45.960	0.746	3.077	0.805	3.350
46.188	0.746	3.077	0.805	3.350
46.415	0.746	3.077	0.805	3.350
46.643	0.746	3.077	0.805	3.350
46.870	0.746	3.077	0.805	3.350
47.098	0.746	3.077	0.805	3.350
47.325	0.746	3.077	0.805	3.350
47.553	0.746	3.077	0.805	3.350
47.780	0.746	3.077	0.805	3.350
48.008	0.746	3.077	0.805	3.350
48.235	0.746	3.077	0.805	3.350
48.463	0.746	3.077	0.805	3.350
48.690	0.746	3.077	0.805	3.350
48.918	0.726	2.987	0.805	3.350
49.145	0.726	2.987	0.805	3.350
49.373	0.726	2.987	0.805	3.350
49.600	0.726	2.987	0.805	3.350
49.828	0.726	2.987	0.805	3.350
50.055	0.726	2.987	0.805	3.350

Table C-2.--continued

RAW DATA-GAS VENT 33				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
0.000	3.553	16.020	3.553	16.020
0.228	3.416	15.386	3.298	14.843
0.455	3.357	15.115	3.220	14.481
0.683	3.318	14.934	3.102	13.938
0.910	3.279	14.753	2.984	13.395
1.138	3.220	14.481	2.906	13.033
1.365	3.180	14.300	2.827	12.671
1.593	3.122	14.029	2.788	12.490
1.820	3.063	13.757	2.729	12.219
2.048	3.004	13.486	2.690	12.038
2.275	2.945	13.214	2.631	11.766
2.503	2.906	13.033	2.572	11.494
2.730	2.866	12.852	2.513	11.223
2.958	2.827	12.671	2.474	11.042
3.185	2.807	12.581	2.415	10.770
3.413	2.768	12.400	2.356	10.499
3.640	2.749	12.309	2.297	10.227
3.868	2.729	12.219	2.238	9.956
4.095	2.690	12.038	2.199	9.775
4.323	2.670	11.947	2.140	9.503
4.550	2.631	11.766	2.101	9.322
4.778	2.591	11.585	2.061	9.141
5.005	2.552	11.404	2.042	9.051
5.232	2.533	11.313	2.002	8.870
5.460	2.513	11.223	1.963	8.689
5.687	2.474	11.042	1.944	8.598
5.915	2.434	10.861	1.924	8.508
6.142	2.375	10.589	1.885	8.327
6.370	2.336	10.408	1.865	8.236
6.597	2.297	10.227	1.845	8.146
6.825	2.258	10.046	1.845	8.146
7.052	2.238	9.956	1.806	7.965
7.280	2.199	9.775	1.806	7.965
7.507	2.179	9.684	1.787	7.874
7.735	2.140	9.503	1.767	7.784
7.962	2.120	9.413	1.747	7.693
8.190	2.081	9.232	1.728	7.603

Table C-2.--continued

RAW DATA-GAS VENT 33 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
8.417	2.061	9.141	1.728	7.603
8.645	2.042	9.051	1.708	7.512
8.872	2.022	8.960	1.688	7.422
9.100	2.002	8.870	1.669	7.331
9.327	1.963	8.689	1.669	7.331
9.555	1.963	8.689	1.649	7.241
9.782	1.944	8.598	1.649	7.241
10.010	1.924	8.508	1.629	7.150
10.237	1.885	8.327	1.610	7.060
10.465	1.885	8.327	1.610	7.060
10.692	1.865	8.236	1.590	6.969
10.920	1.845	8.146	1.590	6.969
11.147	1.845	8.146	1.571	6.879
11.375	1.826	8.055	1.571	6.879
11.602	1.806	7.965	1.551	6.788
11.830	1.787	7.874	1.551	6.788
12.057	1.767	7.784	1.531	6.698
12.285	1.767	7.784	1.531	6.698
12.512	1.747	7.693	1.531	6.698
12.740	1.728	7.603	1.512	6.607
12.967	1.728	7.603	1.512	6.607
13.195	1.708	7.512	1.492	6.517
13.422	1.708	7.512	1.492	6.517
13.650	1.688	7.422	1.492	6.517
13.877	1.688	7.422	1.472	6.426
14.105	1.669	7.331	1.472	6.426
14.332	1.649	7.241	1.453	6.336
14.560	1.649	7.241	1.453	6.336
14.787	1.629	7.150	1.453	6.336
15.015	1.629	7.150	1.453	6.336
15.242	1.610	7.060	1.433	6.245
15.470	1.610	7.060	1.433	6.245
15.697	1.590	6.969	1.413	6.155
15.925	1.590	6.969	1.413	6.155
16.152	1.571	6.879	1.413	6.155
16.380	1.571	6.879	1.413	6.155
16.607	1.571	6.879	1.394	6.064

Table C-2.--continued

RAW DATA-GAS VENT 33 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
16.835	1.551	6.788	1.394	6.064
17.062	1.551	6.788	1.394	6.064
17.290	1.531	6.698	1.374	5.974
17.517	1.531	6.698	1.374	5.974
17.745	1.512	6.607	1.374	5.974
17.972	1.512	6.607	1.374	5.974
18.200	1.492	6.517	1.355	5.883
18.427	1.492	6.517	1.355	5.883
18.655	1.492	6.517	1.355	5.883
18.882	1.492	6.517	1.335	5.792
19.110	1.472	6.426	1.335	5.792
19.337	1.472	6.426	1.335	5.792
19.565	1.453	6.336	1.335	5.792
19.793	1.453	6.336	1.335	5.792
20.020	1.453	6.336	1.315	5.702
20.248	1.453	6.336	1.315	5.702
20.475	1.433	6.245	1.315	5.702
20.703	1.433	6.245	1.315	5.702
20.930	1.413	6.155	1.296	5.611
21.158	1.413	6.155	1.296	5.611
21.385	1.413	6.155	1.296	5.611
21.613	1.413	6.155	1.296	5.611
21.840	1.394	6.064	1.296	5.611
22.068	1.394	6.064	1.276	5.521
22.300	1.374	5.974	1.276	5.521
22.528	1.374	5.974	1.276	5.521
22.750	1.355	5.883	1.276	5.521
22.978	1.355	5.883	1.256	5.430
23.205	1.355	5.883	1.256	5.430
23.433	1.335	5.792	1.256	5.430
23.660	1.335	5.792	1.256	5.430
23.888	1.335	5.792	1.256	5.430
24.115	1.335	5.792	1.256	5.430
24.343	1.335	5.792	1.237	5.340
24.570	1.315	5.702	1.237	5.340
24.798	1.315	5.702	1.237	5.340
25.025	1.315	5.702	1.237	5.340

Table C-2.--continued

RAW DATA-GAS VENT 33 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
25.253	1.315	5.702	1.237	5.340
25.480	1.296	5.611	1.237	5.340
25.708	1.296	5.611	1.217	5.249
25.935	1.296	5.611	1.217	5.249
26.163	1.296	5.611	1.217	5.249
26.390	1.276	5.521	1.217	5.249
26.618	1.276	5.521	1.217	5.249
26.845	1.276	5.521	1.198	5.159
27.073	1.276	5.521	1.198	5.159
27.300	1.276	5.521	1.198	5.159
27.528	1.256	5.430	1.198	5.159
27.755	1.256	5.430	1.198	5.159
27.983	1.256	5.430	1.178	5.068
28.210	1.256	5.430	1.178	5.068
28.438	1.256	5.430	1.178	5.068
28.665	1.256	5.430	1.178	5.068
28.893	1.237	5.340	1.178	5.068
29.120	1.237	5.340	1.178	5.068
29.348	1.237	5.340	1.178	5.068
29.575	1.237	5.340	1.178	5.068
29.803	1.237	5.340	1.178	5.068
30.030	1.217	5.249	1.158	4.978
30.258	1.217	5.249	1.158	4.978
30.485	1.217	5.249	1.158	4.978
30.713	1.217	5.249	1.158	4.978
30.940	1.217	5.249	1.158	4.978
31.168	1.217	5.249	1.139	4.887
31.395	1.198	5.159	1.139	4.887
31.623	1.198	5.159	1.139	4.887
31.850	1.198	5.159	1.139	4.887
32.078	1.198	5.159	1.139	4.887
32.305	1.198	5.159	1.119	4.797
32.533	1.178	5.068	1.119	4.797
32.760	1.178	5.068	1.119	4.797
32.988	1.178	5.068	1.119	4.797
33.215	1.178	5.068	1.119	4.797

Table C-2.--continued

RAW DATA-GAS VENT 33 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
33.443	1.178	5.068	1.119	4.797
33.670	1.178	5.068	1.119	4.797
33.898	1.178	5.068	1.099	4.706
34.125	1.158	4.978	1.099	4.706
34.353	1.158	4.978	1.099	4.706
34.580	1.158	4.978	1.099	4.706
34.808	1.158	4.978	1.099	4.706
35.035	1.158	4.978	1.099	4.706
35.263	1.139	4.887	1.099	4.706
35.490	1.139	4.887	1.099	4.706
35.718	1.139	4.887	1.099	4.706
35.945	1.139	4.887	1.099	4.706
36.173	1.139	4.887	1.080	4.616
36.400	1.139	4.887	1.080	4.616
36.628	1.139	4.887	1.080	4.616
36.855	1.119	4.797	1.080	4.616
37.083	1.119	4.797	1.080	4.616
37.310	1.119	4.797	1.080	4.616
37.538	1.119	4.797	1.080	4.616
37.765	1.119	4.797	1.080	4.616
37.993	1.119	4.797	1.080	4.616
38.220	1.099	4.706	1.080	4.616
38.448	1.099	4.706	1.069	4.566
38.675	1.099	4.706	1.069	4.566
38.903	1.099	4.706	1.069	4.566
39.130	1.099	4.706	1.069	4.566
39.358	1.099	4.706	1.069	4.566
39.585	1.099	4.706	1.069	4.566
39.813	1.099	4.706	1.069	4.566
40.040	1.099	4.706	1.069	4.566
40.268	1.099	4.706	1.069	4.566
40.495	1.080	4.616	1.069	4.566
40.723	1.080	4.616	1.069	4.566
40.950	1.080	4.616	1.045	4.456
41.178	1.080	4.616	1.045	4.456
41.405	1.080	4.616	1.045	4.456
41.633	1.080	4.616	1.045	4.456

Table C-2.--continued

RAW DATA-GAS VENT 33 (continued)				
	PUMP SLUG TEST 1		PUMP SLUG TEST 2	
Time (min)	Transducer Voltage	Depth Below Static (ft)	Transducer Voltage	Depth Below Static (ft)
41.860	1.060	4.525	1.045	4.456
42.088	1.060	4.525	1.045	4.456
42.315	1.060	4.525	1.045	4.456
42.543	1.060	4.525	1.045	4.456
42.770	1.060	4.525	1.045	4.456
42.998	1.060	4.525	1.045	4.456
43.225	1.040	4.435	1.024	4.359
43.453	1.040	4.435	1.024	4.359
43.680	1.040	4.435	1.024	4.359
43.908	1.040	4.435	1.024	4.359
44.135	1.040	4.435	1.024	4.359
44.363	1.021	4.344	1.024	4.359
44.590	1.021	4.344	1.024	4.359
44.818	1.021	4.344	1.024	4.359
45.045	1.021	4.344	1.024	4.359
45.273	1.021	4.344	1.024	4.359
45.500	1.021	4.344	1.024	4.359
45.728	1.021	4.344	1.003	4.260
45.955	1.021	4.344	1.003	4.260
46.183	1.021	4.344	1.003	4.260
46.410	1.021	4.344	1.003	4.260
46.638	1.021	4.344	1.003	4.260
46.865	1.001	4.254	1.003	4.260
47.093	1.001	4.254	1.003	4.260
47.320	1.001	4.254	1.003	4.260
47.548	1.001	4.254	1.003	4.260
47.775	1.001	4.254	1.003	4.260
48.003	1.001	4.254	1.003	4.260
48.230	1.001	4.254	1.003	4.260
48.458	1.001	4.254	0.981	4.162
48.685	0.982	4.163	0.981	4.162
48.913	0.982	4.163	0.981	4.162
49.140	0.982	4.163	0.981	4.162
49.368	0.982	4.163	0.981	4.162
49.595	0.982	4.163	0.981	4.162
49.823	0.982	4.163	0.981	4.162
50.050	0.982	4.163	0.981	4.162

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Kimberly L. Shank was born at Andrews Air Force Base in Washington D.C. on January 21, 1963, to Gerald L. and Rebecca A. Shank. She graduated from State College Area High School, State College, Pennsylvania, in 1980.

She was enlisted in the United States Navy in April, 1981, and was awarded a Naval Reserve Officers Training Corps scholarship in 1982. She received a Bachelor of Science degree in math and physics from Jacksonville University, Jacksonville, Florida, and a Bachelor of Civil Engineering from Georgia Institute of Technology, Atlanta, Georgia, in September, 1987. She was commissioned in the United States Navy following graduation.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

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